SWEETPOTATO STORAGE

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CONTENTS

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SWEETPOTATO STORAGE

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NEED FOR SWEETPOTATO STORAGE

Sweetpotatoes have an important place in the human diet. Storage of them benefits both the producer and the consumer by making them available throughout the year. During 1961–65, sweetpotato production in the United States averaged about 900,000 tons a year with a farm value near $75 million. Not all of this crop was stored since approximately 25 percent was marketed soon after harvest and another 25 percent processed (primarily canned). A small part of the processed portion of the crop was cured and stored before being processed. The remaining 50 percent of the crop, or approximately 450,000 tons, was stored for marketing during the winter and spring or was used as "seed" to produce the next crop. The primary purposes of curing and storing sweetpotatoes are to permit orderly marketing during the several months that follow harvesting and to promote high plant production from seed roots.

Proper curing and storage aid in assuring good market quality, as exemplified by good appearance, desirable culinary quality, and freedom from defects. If improper conditions for curing and storage are used, losses from decay, shrinkage, and poor appearance can be tremendous and culinary quality reduced. It is obvious, therefore, that a well-designed, well-managed storage facility serves a necessary function by helping to maintain the quality of the sweetpotatoes after harvest with a minimum of loss (*97*, *98*, *109*, *119*).[1]

To get the most satisfactory results in storing sweetpotatoes, the following six points must be observed.

- The storage house and containers must be clean.
- Roots showing disease, especially black rot, should be kept out of storage.
- The crop must be harvested in time to avoid low-temperature or wet-soil injury.
- The sweetpotatoes should not be cut, bruised, or skinned during harvesting, and during filling, stacking, hauling, and handling storage containers.
- The sweetpotatoes should be placed under proper curing conditions promptly after harvest without exposure to conditions that cause sunscalding, chilling, or desiccation.
- The proper storage conditions must be maintained after curing.

REQUIREMENTS FOR SWEETPOTATO STORAGE

A Clean Storage House and Clean Containers

Before sweetpotatoes are placed into the storage house, all old or decayed sweetpotatoes and other debris should be removed. All storage containers should be emptied, if they already have not been, and the floor of the storage house flushed or swept. False floors should be removed and cleaned underneath. Any repairs that are needed should be made.

Disinfection of Storage and Containers

Fumigating the storage is not necessary if it is cleaned as indicated. The most common storage losses result from infections of the soft rot organisms (*Rhizopus* spp.) and the end or surface rot organisms (*Fusarium* spp.). These organisms are almost universally present. No evidence is available to indicate that fumigating the storage and storage containers will control these diseases.

If black rot is present, or suspected as being present, the storage house and storage containers should be treated to eliminate the disease before they are used again. The black rot organism is sensitive to heat. It is killed by exposing diseased roots or contaminated containers to temperatures of 110° to 115° F. for 24 hours (*19*, *26*, *66*) or for 6 hours at 122° (*92*). Scurf, another sweetpotato disease, is also killed by exposing the roots for 6 hours at 122° (*92*). To be sure the temperature is

[1] Italic numbers in parentheses refer to Literature Cited, p. 31.

high enough in all parts of the storage house, it should be warmed to 120° for 24 hours or longer. Only a small amount of heat would be needed to do this at low cost if it were done on a warm summer day after all the previous crop had been removed. Any objects, such as paint or aerosol containers, that could be damaged by the heat should be removed from the storage before it is heated.

Storage of Sound, Disease-Free Roots

To successfully store sweetpotatoes, roots must be free of disease. Many diseases attacking sweetpotatoes occur first in the field. By following approved cultural practices, these diseases can be controlled. No field, however, is completely disease free. At harvest, then, the roots should be inspected before they are placed into storage containers and those diseased or unmarketable kept out.

Roots affected with growth cracks do not keep well (*86*) and should not be stored. Some roots with scurf should not be stored, although small amounts are allowed in the U.S. No. 1 grade (up to 15 percent of the surface) and larger amounts, but not over 15 percent of the surface of any root, in No. 2 commercial grades. Grade standards (*124*, *125*, *126*) and marketing outlets should be considered in handling these roots. Since the scurf fungus does not penetrate into the roots, the eating quality is not affected. But when stored, scurfy roots shrink more rapidly than others and may become unmarketable. Although this disease does not spread sufficiently from diseased to sound roots to cause a problem, the infected areas may enlarge and new infections may appear during storage when the humidity is high, making these roots unmarketable. This does not occur, however, when the humidity is low (*24*).

Infection by the organism causing black rot occurs in the field. However, the disease can spread during harvesting from diseased to healthy sweetpotatoes so the presence of black rot lesions in a crop at harvest, even in small amounts, may lead to large losses in storage. Usually it is desirable to market the sound roots from such a crop as quickly as possible. In this way any infections occurring at harvest are not given an opportunity to grow and spoil the roots.

HARVEST TO AVOID INJURY TO THE ROOTS

Sweetpotatoes may be harvested whenever they reach a salable size. Under good growing conditions, harvesting may begin 90 to 100 days after planting of some varieties and continue until well after frost has killed the vines and leaves (*28*, *33*). Injuries to the roots detract from their value and cause losses. One usually thinks of injuring sweetpotatoes physically or mechanically; but they may also be injured in several other ways that impair their keeping quality, and, at times, their culinary quality, too.

Injury From Wet Soil

Rainfall that produces saturated or nearly saturated soil conditions causes carbon dioxide to accumulate in the roots (*69*). Sometimes this is accompanied by a depletion of oxygen in the roots also. When considerable amounts of carbon dioxide are accumulated in the roots, wounds heal slowly, if at all, even when given favorable conditions after harvest. Such sweetpotatoes are especially subject to soft rot.

Wet soil may injure the roots at any time, either before or after frost. Because heavy rains often accompany frosts that kill the vines and leaves, there is, at times, an association of frost with the damage. Since the damage caused by wet soils is associated with an accumulation of carbon dioxide in the roots, damage is produced more quickly in warm, wet soil than in cool, wet soil. Loss or removal of the vines increases the damage.

Not all roots damaged by wet soil decay, but those that do not often have an off-flavor or noxious odor when cooked.

Injury From Cold Soil

Sweetpotatoes freeze at about 30° F. and are ruined. They are injured at temperatures below 55°, especially those below 45°. Many growers delay digging until the first light frost occurs. Some, because of large acreage, cannot harvest at least part of the crop until after frost has damaged or killed the leaves and vines. In general, no damage will result unless frost injures the top of exposed roots or the air temperature drops low enough to freeze the top inch or two of the soil and the root tissue in this layer. If the roots are dug promptly after a light frost, they will keep as well as before the frost. The soil temperature at the time of the first light frosts usually will be near 60° in the vicinity of most of the roots (*69*).

Harvesting should be concluded as soon as possible after frost kills the vines and leaves. Destruction of the leaves prevents an increase in yield, and delaying harvest provides an opportunity for wet or cold weather to damage the undug portion of the crop.

Injuries From Harvesting and Handling

The quality of sweetpotatoes coming out of storage is influenced by the kind and amount of injuries inflicted during harvesting and handling. Bruises and abrasions must be kept at a minimum. The sweetpotato root is covered by a thin, delicate skin that is easily removed or broken. The sweetpotatoes may be cut or bruised so as to produce crushed tissue. High levels of fertilization that cause late vine growth has been associated with an increase in decay, apparently because the roots were more easily damaged than when grown with lower fertility. (*25*). Potash levels influence keeping quality slightly (*29*).

Although curing, described below, usually heals injuries quickly, the injured roots are not as attractive as those uninjured. Severely damaged areas, especially those involving crushed tissue, are slow to heal even with ideal curing conditions (*120*, *128*). Therefore, the amount of decay that develops often reflects the severity and extent of injuries received at harvest and the degree to which good curing conditions are provided.

Exposure of sweetpotatoes to bright sun, chilling temperatures, or drying winds for periods sufficient to damage tissue makes healing more difficult and may result in considerable loss from decay (*84*, *94*, *103*). On a warm day an hour or more of exposure to bright sunlight will cause temperatures at exposed surfaces to rise over 100° F. and increase the amount of surface rot in storage. Leaving roots overnight in the field when air temperatures drop near freezing or letting them lie in the field for several hours when dry winds are blowing also will increase surface rot on most varieties.

Harvesting Equipment

Various methods are used for digging sweetpotatoes (*14*, *87*, *105*, *107*, *110*, *111*, *131*). Usually the first step is to remove as much of the vines and leaves of the plant as necessary to allow digging and picking up the sweetpotatoes with minimum interference. Frequently the vines are removed by barring off the hill on each side with disks and passing a rotary mower over the hill (fig. 1).

Several other practices are also used to cut the vines and leaves. One is using a blade mounted in a drag and flails of rubber or chain. Another, and probably the best, is to cut the vines with an 8-inch shielded rolling colter set shallow and offset 5 to 6 inches from the center of the hill. The shield prevents the colter from going too deep and forces the vines down against the soil where they will be cut cleanly. On a turning plow the colter is lined up with the plow landside. A 16- to 18-inch tractor-drawn turning plow with the shin of the plow lined up with the off edge of the hill provides a good complement with the shielded rolling colter. In any event, the cutting must be at the side of the hill or across the top without cutting into the hill proper where the marketable roots are located.

Because turning the hill with a plow usually exposes only part of the sweetpotatoes, considerable hand labor is needed to scratch the potatoes out, sort them, and place them in storage containers. In areas where soils are light, part of the moldboard section of the plow is cut away and a rotary spiral installed to help sift soil from the potatoes. The sweetpotatoes should not be thrown into heap rows or handled any more than necessary. Soft cotton gloves are usually worn to protect the sweetpotatoes from being damaged by fingernails.

White-potato diggers are often used to harvest sweetpotatoes because they usually expose most of the roots. In dry or sandy soil, however, these diggers often damage the roots so much that the roots become unacceptable for marketing. In an effort to reduce such injury, several modifications have been made of these diggers. Short-bed diggers, mounted on the 3-point hitch of a tractor are used in many areas. The hydraulic system of the tractor can be used to carefully control the depth of digging so that soil can be kept on the shaker chain to cushion the potatoes until just before the roots fall back onto the ground. If the vines are removed before digging by barring off the hill on each side and the operator is careful to keep soil on the shaker chain, bruising can be kept as low as or lower than when a moldboard plow or middle-buster is used to dig. Under normal field conditions as much as 30 to 40 percent less time may be required to sort and pick up sweetpotatoes when a short-chain tractor-mounted digger is used than when a moldboard plow is used. In addition, up to 25 percent more marketable roots may be obtained following the short-chain tractor-mounted digger (*107*).

To further reduce the labor required for digging, sorting, and crating sweetpotatoes, several types of harvesters have been developed. On many of these harvesters the sweetpotatoes are placed in crates by hand. Placing them in crates, bulk (½ ton) boxes, or bulk trucks directly from conveyors usually causes too much injury for sale on the fresh market. Considerable handwork is necessary to sort the roots out of the soil and vines and to place them into crates. The filled crates are stacked temporarily on platforms located either at the side or at the rear of the harvester (fig. 1). Some platforms have been designed to hold one or two pallets on which the crates are stacked. The palletized crates are removed with a tractor-mounted fork and placed onto a truck that hauls them to the storage house.

Most mechanical harvesters used to harvest sweetpotatoes for processing plants cause more injury than can be tolerated for roots going to the fresh market or into storage.

Depending upon field conditions, yield, type of harvester, and factors related to management, a

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FIGURE 1.—Harvester with filled crates on racks at the side of the machine. Rotary mower at left is followed by tractor (not in view) barring off the sides of the hills.

harvester with 6 to 12 laborers usually can harvest about 1 or 2 acres of sweetpotatoes a day.

Tractor-drawn sulky-type harvesters require several feet of turning area at the ends of the rows and are not suited for use in fields with short rows. Terraces, constructed to prevent soil erosion, usually cause problems where harvesters are used.

Harvesters are usually equipped with a standard type of white-potato-digger shovel followed by an elevator chain that is gently agitated to remove most of the soil. On some models the elevator chain becomes horizontal after attaining a specified elevation and extends on back through the harvester. On others the elevator drops the roots, soil, and vines carried up the elevator onto a second link-chain conveyor which runs back to the rear of the harvester. To reduce injury to the roots, the links may be covered with rubber or made of sections of wood that enables more soil to be carried. On some harvesters a rubberized belt is used as a second or cross conveyor after most of the soil has been allowed to fall back to the field to prevent injuries to the roots.

Storage Containers

Inherent in the harvesting and handling operations is the container used for storing the sweetpotatoes. Three types commonly used are (1) the tub-bushel basket, (2) the James or Hybrid crate or a modification of it, and (3) the Durabox, which is available in two styles.[2] These containers are also used for shipping sweetpotatoes to market. Occasionally, about a ½-ton pallet or bulk box is used. Burlap bags are not recommended for storing sweetpotatoes as they remove too much skin from the roots.

The tub-bottom bushel basket has been used for many years, especially in Eastern United States. Crates, usually Duraboxes, are rapidly replacing baskets for two reasons: The sweetpotatoes receive much less injury in the crates than in the baskets and the crates may be palletized and handled with forklift equipment to save labor.

The James or Hybrid crate (fig. 2) has been used for several years in Louisiana and in neighboring States as a storage and shipping container. These containers were designed as shipping containers. As such, they can be packed with a bulge on the top and then stacked for shipment on their sides, at which time the box has its greatest structural strength for supporting weight. When

[2] Trade names are used solely in this publication for the purpose of providing specific information. Mention of a trade name does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture or an endorsement by the Department over other products not mentioned.

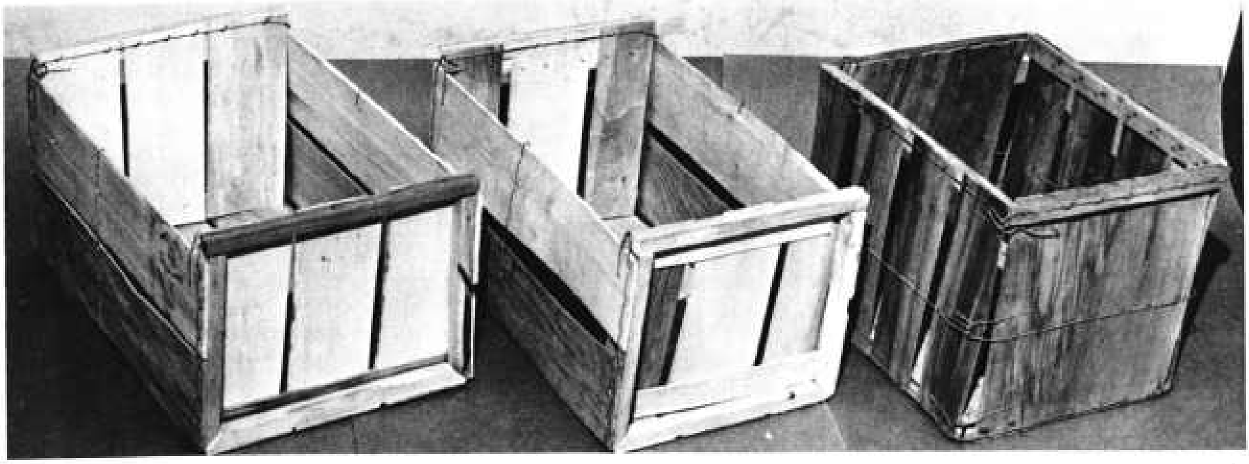

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FIGURE 2.—Crates for harvesting and storing sweetpotatoes, left to right: Storage Durabox, 3-way Durabox, Hybrid crate.

stacked upright as a storage container, these crates may be stacked 10 high (fig. 3).

If the Hybrid crates are stacked 12 or more high, the bottom crates usually are crushed (*108*). The one-bushel Hybrid crate has a volume of about 2,460 cubic inches and outside dimensions of 14¼ by 16½ by 13⅛ inches high without a bulge. They cannot be nested 1 in 2 when empty (3 crates in the space occupied by 2; that is one crate is placed inside the other two crates that are placed with the openings toward each other).

Two kinds of Duraboxes are used. One is designed for field and storage use only; the other for field, storage, and shipping use. They are commonly referred to as storage and 3-way boxes, respectively. Both are designed with the supporting cleats in the ends (fig. 2). Consequently, they will support considerable weight when assembled properly, and are suited to palletizing and high stacking.

The 3-way Durabox measures 20¾ by 13⁷⁄₁₆ by 11⅞ inches high with a capacity of about 2,593 cubic inches. The bottom and lower side shooks are ⅛-inch thick and the top side shooks are ⅙-inch thick. A stapled wire near the center of the box helps support the bottom and sides, which tend to give with the weight of the sweetpotatoes. With the addition of a lid, label, and paper strips, the container can be used for shipping.

The storage Durabox is slightly larger than the 3-way Durabox and made with heavier shooks. The outside dimensions are 20¾ by 14¹³⁄₁₆ by 11½ inches high with a capacity of about 2,729 cubic inches. The bottom and lower side shooks are ⅙-inch thick and the top side shooks are ⁷⁄₃₂-inch thick. A wire stapled around the box helps support the sides and bottom, which usually do not give noticeably when the container is full of sweetpotatoes.

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FIGURE 3.—Method of stacking Hybrid crates of sweetpotatoes on a slatted floor raised above the earth floor.

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The approximate weight of sweetpotatoes that may be stored in the containers at harvest can be estimated by dividing the calculated cubic-inch capacity by 50, since one pound of root will occupy about 50 cubic inches. Roots of the variety Nugget tend to be considerably heavier per unit volume than other varieties, so the containers will hold more weight of Nugget roots than of other varieties.

Bulk handling of sweetpotatoes in palletized bins of about ½- to 1-ton capacity is relatively common for sweetpotatoes going to canneries, but not for those intended for the fresh market. However, some growers do pick up sweetpotatoes in a field container and pour them carefully into pallet boxes in the field. Better methods of filling and emptying the pallet bins are needed.

Containers should not be filled to the point where roots will be damaged by stacking one box on another. The box, rather than the sweetpotatoes, should support the weight of additional boxes. Storage containers, such as bushel baskets, James or Hybrid crates, and 3-way Duraboxes, can generally be used once for storage and once for marketing, if care is taken to prevent them from breaking and discoloring. The effects of rain, soil, decaying roots, or mold growth during harvesting and storage often make wooden containers unattractive.

Provisions must be made for storing empty containers from one season to the next. The number of containers held over from one season to the next depends primarily upon the kind of container, the number shipped to market, and the number damaged too much for reuse. The space occupied by the empty containers is, at times, a factor which influences overall management of the storage.

Handling Equipment

Because of the trend toward palletization of sweetpotato containers, pallet design and use must be considered in connection with the storage containers and also in storage house design and management. Obviously the pallet must be designed for the storage container and, then, the storage designed to permit efficient handling and storing of the palletized containers as a unit. If a storage is already available and is suitable for a forklift operation, the planning may of necessity be in the reverse order to avoid loss of considerable storage area.

There are many factors to consider in selecting a pallet size. The dimension that coincides with the direction in which the forks of the forklift penetrate the pallet (that is, the dimension across the field-truck bed) should be 48 inches or less. Thus, two pallets across the truck bed will conform to the 8-foot allowable maximum width of the load on the highway and the center of the pallet load will not exceed the 24-inch load center designed into most forklift equipment. The other dimension is usually about 48 inches and preferably a little less so that the load on the pallet will not cause it to bend appreciably beyond where the forks support the pallet.

Pallets for the storage Durabox are usually 44 by 44 inches (*112*). The boxes are stacked with their ends toward the sides of a field truck to prevent the boxes from rocking off when the truck turns corners. Both types of Duraboxes are 21 inches long and six of them will stack in a single layer on a pallet with approximately 1 inch left on each side of the pallet at the ends of the boxes. Since the strength of the Durabox is in the ends, there is a little room left for some margin of error in stacking to be sure the ends of the boxes are on the pallet. The 44- by 44-inch dimensions permit stacking the pallets in the storage in any direction without special consideration of space utilization necessary with rectangular pallets. Although the same size of pallet may be used with the 3-way Durabox, which is slightly narrower than the storage Durabox, a 2- by 4-inch board is needed between pallets to properly aline the boxes on the pallets. Therefore, a 40- by 44-inch pallet is used in some storages with the 3-way Durabox.

Another consideration is the bulk of the palletized unit. Duraboxes stacked six in a layer and five layers high produce a gross weight approaching 1 ton (30 times approximately 60 pounds plus a pallet weighing about 100 pounds).

The storage Durabox will stack and handle satisfactorily five high on a pallet; the 3-way Durabox, four high, although stacking five high is preferred if the storage house will permit it. Stacking five high conserves space, pallets, and forklift operation. If the 3-way Duraboxes are stacked five high, the top layer should be tied with a wire or string to keep the boxes in place. This is needed because the 3-way Durabox is narrower than the storage type and because the boxes cannot be interlocked.

Allowing 6 inches for the thickness of a pallet, three pallets of storage Duraboxes stacked on one another are nearly 16 feet tall; and if 3-way Duraboxes are used, the total height is slightly more than 16 feet. Some clearance must be allowed for placing the top pallet in position and for ventilation, so the ceiling should be 17½ or more feet from the floor (fig. 4).

For handling a 1-ton gross pallet load, a 2,000-pound forklift may be used, but this size of truck is often too unsteady and taxes the unit when placing a pallet in the third layer of a stack. A 3,000-pound forklift is safer, quicker, and nearly as maneuverable as a 2,000-pound one. Some operators prefer a 4,000-pound forklift truck if it can be turned and handled easily in the storage area. In any event, the lift must be capable of elevating the forks to a height about 6 inches above the

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FIGURE 4.—Placing topmost pallet of Duraboxes in position, five layers of boxes per pallet.

boxes upon which the highest pallet will be placed. In the illustration of the Duraboxes stacked five layers high (fig. 4), the height of two pallets is slightly over 10 feet. Fortunately, the standard extension of many types of forklifts is 10½ feet or more.

For rapidity and accuracy in stacking pallets, the lift should be equipped with a "sideshifter." The fork should be long enough to reach all supporting boards of the pallet. In the Durabox illustration (fig. 4), the fork would be 42 inches, but 36-inch forks may suffice if wide boards are used at the edge of the pallets. The shorter forks permit a shorter turning radius for the truck, which is important in some storage areas. A sideshifter will reduce the turning radius necessary also. A rack or set of crash bars on the forklift truck will help to prevent injury to the operator if boxes fall off the pallets.

Since a forklift truck will have many uses around a storage house, especially where sweetpotatoes are graded and shipped to market, one should be selected with care.

Handling sweetpotatoes in properly palletized field boxes with a forklift truck usually produces very little injury to the roots. The field trucks may be unloaded quickly at the storage house, and large quantities of sweetpotatoes may be placed in storage with relatively little labor other than the forklift operator. Handling sweetpotatoes with a forklift truck is so gentle that the sweetpotatoes may be moved after curing practically injury free. This in turn has permitted the development of a system of storage-house management and design utilizing separate curing and storage facilities (p. 30).

CURING

Sweetpotatoes should be cured immediately after harvest, preferably at 85° F. and a relative humidity of 85 to 90 percent for 4 to 7 days. Sufficient exchange of air in the curing room should be allowed to prevent the accumulation of carbon dioxide produced by the roots or the depletion of oxygen consumed by them. If condensation is excessive, it is removed by ventilation.

The primary purpose of curing is to heal injuries so that the sweetpotatoes remain in good condition for marketing during the winter and to preserve "seed" roots for the next crop. Healing takes place rapidly at 85° F. and 85 to 90 percent relative humidity (*3*, *6*, *21*, *77*, *78*, *83*, *101*, *128*). Curing should start as soon after harvest as possible to heal injuries before disease-producing organisms gain entrance (*70*). Healing involves production of cells that are very much like the skin in their ability to prevent infection. These new cells form in a layer just below the surface of the injuries. Because this layer is corky, it is commonly called wound cork. Healing is more rapid under clean cuts and skinned areas than in deep wounds where tissue is crushed (*120*, *128*). The rate of healing differs a little among varieties.

At 85° to 90° F. wound cork begins to form in 2 days and is well developed in 5 or 6 days. At lower or higher temperatures than this, wound cork forms less rapidly. Above 95° very little, if any, wound cork develops and such temperatures should be avoided. Satisfactory wound-cork formation takes about 4 to 7 days at 85°, 8 to 10 days at 80°, 15 to 20 days at 75°, and 25 to 30 days at 70°. At 55° or below, wound cork does not form. Slow formation of wound-cork increases the opportunity for decay-producing organisms to gain entrance to the root before the layer is sufficiently well formed.

Because the layer of wound cork forms near the surface of wounds, desiccation of the wounds retards such formation by making the cork form several cells deeper, or, if the wound dries rapidly, prevents the formation of wound cork by desiccating the cells that form the cork layer. Usually, a relative humidity below 70 percent retards healing, causes high weight losses, and makes injuries dark, sunken, and unsightly. Relative humidity near saturation (95 to 100 percent) often allows considerable condensation on storage walls and ceiling, and may cause discoloration of the surface of the roots (*41*). The relative humidity around the roots in a storage container is usually slightly higher than that in the air around the containers or in the rest of the room (*82*).

A sticky, milklike juice often exudes from injuries (*57*). This juice dries in a few hours and may appear to close the wound but actually offers little or no protection against rotting. Also, the presence of a dried and hardened surface over a wound is no indication that the wound has been healed, although this surface may retard the entrance of decay-producing organisms for a time. Phenolic substances have been associated with wound-cork formation but their role in producing resistance to infection is not established (*22, 89*).

The conditions to which the roots are subjected for the first 3 or 4 days after harvest determine the degree of success in controlling decay by curing (*85, 90*). Long curing periods at temperatures below 85° F. do not compensate for the difference in temperature. Curing may be extended to set the skin of the roots if they are to be graded and shipped soon after harvest. During the last few days of the extended cure, the relative humidity may be reduced to dry the roots some in an effort to help set the skin.

At harvesttime the skin of the sweetpotato is thin and delicate and easy to slip or remove. Often roots that are run over grading equipment lose noticeable amounts of their skin. The skin usually slips more easily 2 or 3 days after harvest than at harvest; but as curing progresses, the skin slips less and less easily and eventually tightens (*123*).

The ease with which the skin slips at harvest and the rate at which it develops adherence to the root vary considerably. Factors influencing this are not well understood, but roots should be protected from being skinned during preparation for market. It is important that conditions of curing and storage that speed setting the skin be maintained. Experienced storage-packinghouse operators usually allow 4 to 6 weeks after harvest to set the skin through proper curing and storage. Some operators indicate that drying roots after curing aids in setting the skin when grading must be done soon after curing.

By the time roots have been cured (healed) they usually have a few short sprouts and a somewhat velvety feel. If curing conditions are maintained, these sprouts will grow and need to be removed during grading. In addition, prolonging curing will reduce the storage life of the roots. Reducing the temperature in the storage house to 55° to 60° F. will prevent further sprouting. Some varieties (Nugget, Julian) sprout more slowly than others (Jersey Orange, Goldrush).

The organism causing black rot, if present in the field at harvest, may infect roots, and these roots even though they are cured properly develop typical black-rot spots (*75*). While it is possible to prevent black-rot infection by curing infected roots at 95° F. (*64*) or to kill the organism by holding the roots at temperatures over 100° (*19, 26, 66, 92*), neither of these treatments has proved practical for commercial use because the temperature must be closely controlled. If black rot is present at harvest, even in very small amounts, it is usually advisable to market the sound sweetpotatoes as soon as possible without curing. Fortunately, this disease is not as prevalent as formerly because control measures are followed during production. If the disease is present, it may be controlled reasonably well on roots going to market by sanitation practices (*100*) and by treatment with SOPP (sodium o-phenylphenate (*65*)).

Only a small amount of ventilation is required during curing to prevent an accumulation of carbon dioxide or a depletion of oxygen. Usually sufficient exchange of air takes place in the normal opening and closing of doors or through infiltration. However, as better or tighter storage houses are constructed or rooms are designed specifically for curing, presprouting, or refrigerated storage, requirements of air exchange must be considered.

During curing at 85° F., sweetpotatoes that are sound—that is, not excessively damaged by handling, wet soil, or chilling—consume oxygen at a rate close to 2 cubic feet per ton per day or the amount of oxygen in 10 cubic feet of air. Equivalent amounts of carbon dioxide are given off. This amounts to about 1,250 cubic feet of air per 24 hours for a room holding 5,000 55-pound boxes of sweetpotatoes. But four or five times this amount may be needed because each exchange of air will not completely replace the oxygen consumed or remove the carbon dioxide produced.

If the roots are severely damaged by handling, wet soil, or chilling, the respiration rate may be three to four times faster than that for essentially nondamaged roots (*69*). Decaying roots respire even faster; the rate depends upon how fast the decay develops. If a curing room is filled with roots damaged by rough handling, wet soil, or chilling, it is possible to accumulate carbon dioxide and to deplete the oxygen in the relatively small amount of air left in the room. The storage-house manager should increase ventilation to prevent this from occurring and to remove any excess heat produced by respiration (p. 24).

STORAGE

After curing, sweetpotatoes should be held at 55° to 60° F. with a relative humidity of 85 to 90 percent (*20, 25*). A small amount of ventilation is needed to replace oxygen consumed and to remove carbon dioxide produced. For refrigerated storage, fresh air should be introduced at a rate equal to the cubic-foot capacity of the storage every 2 hours to prevent the accumulation of carbon dioxide (*108*).

The primary purpose of these storage conditions is to minimize physiological and pathological losses. Some of the factors that should be considered have been discussed in connection with curing, but the primary storage problems are development of pithiness, sprouting, chilling, internal cork, and decay.

Weight Loss and Development of Pithiness

Most weight loss is due to evaporation of moisture through the skin. In addition, sweetpotatoes lose weight as a result of respiration that consumes some of the stored food in the root, primarily sugar and starch. During respiration, carbon dioxide and water are given off, thus decreasing the weight of the root (*60*, *127*). For some reason, not fully understood, sweetpotatoes lose water and carbon dioxide in such a manner that the ratio of water to dry matter (such as starch and sugar) in the root changes very little even when the roots are held under widely different conditions of temperature and relative humidity (*41*). Loss of weight is encouraged by high storage temperature and low relative humidity. At 55° to 60° F. and 85 to 90 percent relative humidity, properly cured sweetpotatoes usually lose about 2 percent of their weight per month although differences exists among varieties.

One important aspect of the loss of weight from sweetpotatoes is its association with the development of pithiness in the roots (*5*, *47*). Although sweetpotatoes lose both weight and volume during curing, there is little change in volume during storage (*72*). Consequently, with loss of weight during storage the roots become pithy (fig. 5). Even at harvesttime 5 to 10 percent of the tissue of sweetpotato roots is made up of intercellular spaces (*72*). As weight losses exceed volume losses during storage these spaces increase and eventually become visible—that is, the root becomes pithy. When more than 12 percent of the volume of a root becomes intercellular space, pithiness can usually be seen by cutting the root in half. Obviously, then, weight losses should be kept to a minimum to retain good quality during storage.

Varieties of sweetpotatoes differ in the amount of intercellular space present at harvest as well as in the rate at which this space increases in storage. Varieties that become pithy rapidly, such as Jersey Orange and Gem, should be marketed early in the storage season. Other varieties, such as Porto Rico, Goldrush, and Nugget, do not become pithy rapidly and may be stored from 5 to 7 months.

Sprouting

At any time that temperature in storage rises above 60° F. sprout growth will occur. A high relative humidity encourages growth if the temperature is high enough (see under Curing). Since heat and moisture often collect in the top of a storage room, excessive sprouting is most often noticed in the top layers of sweetpotatoes. Sprout growth contributes to the development of pithiness.

A chemical sprout inhibitor, isopropyl-N(3 chlorophenyl) carbamate, is being tested on a commercial scale and may become available for inhibiting sprout growth during storage. Maleic hydrazide treatment before harvest has proved detrimental (*35*), although it has some effect on apical dominance (*106, 115*).

Chilling

Although reducing physiological activity and decay of the roots by lowering the storage temperature below 55° F. may seem desirable, sweetpotatoes cannot be stored very long at temperatures below 55°. At temperatures from 32° to 50°, they

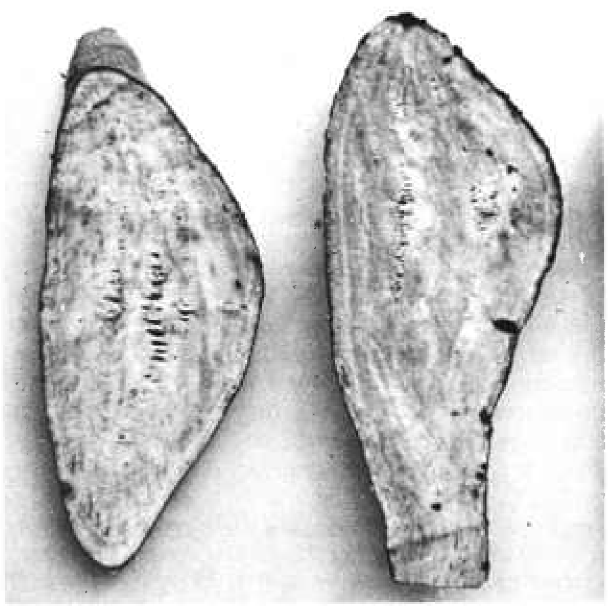

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FIGURE 5.—Pithy condition of sweetpotato root.

develop chilling injury and, like many other crops, freeze and are ruined if held below 30°. A few days at 50° is often not noticeably detrimental, since the extent of the injury is proportional to the decrease in temperature below 55° and the length of time at a chilling temperature (*69*). A day at 32°, however, produces a noticeable effect. Often the effect of chilling is not noticeable until the roots have been returned to the recommended storage temperature.

Chilling injury is expressed in many ways. The most common injuries are internal breakdown (*62*), increased susceptibility to decay (*76*), failure to sprout (*18*, *31*), and impaired culinary quality (*20*, *74*). In addition, chilling produces such physiological responses as loss of ascorbic acid (Vitamin C) (*81*); increase in chlorogenic acid (*81*), which is associated with discoloration upon exposure to air; increase in sugar content, which sometimes is detectable when the roots are cooked (*4*, *69*); inability to synthesize carotene, which usually increases slightly during storage (*38*); and accumulation of carbon dioxide in the root during chilling (*68*); accelerated respiratory activity (*69*, *79*); a change in acidity of the tissue (*71*); and other changes (*9*, *10*, *80*, *99*, *113*).

Varieties differ slightly in their ability to withstand chilling injury. Puerto Rico sweetpotatoes are less susceptible than most other varieties, but all varieties are sufficiently susceptible to make it desirable to avoid chilling conditions.

Pathological Losses

Infections of decay-producing organisms not prevented by curing will progress into various stages of decay during storage. Soft rot is caused by a species of *Rhizopus* that produces a soft decay that consumes the roots quickly, even at 60° F. Surface rot and end rot are caused by species of *Fusarium* that grow slowly; it may take several weeks for an entire root to be destroyed. Several other diseases also are often encountered (*34*, *48*, *52*). Usually the development of decay is more rapid at high temperatures than at 55° to 60°. With few exceptions, the decay-producing organisms do not move from diseased roots to roots healed by curing. A new disease, blister, of unknown origin has been associated with storage of sweetpotatoes (*104*). Blister has been detected more frequently on roots of the Nugget variety than on roots of other varieties.

Internal Cork

Storage temperatures above 60° F. encourage the development of a virus disease of sweetpotatoes that causes the development of corky areas in the roots of susceptible varieties (fig. 6) (*7*, *63*, *67*, *91*, *102*, *129*).

Although some internal cork may be present at harvest, especially if warm weather precedes harvest, during storage the corky areas develop and enlarge at storage temperatures above 60°. The varieties Porto Rico, Goldrush, Georgia Red, and Centennial develop cork, if the virus is present in the roots, at a warm storage temperature. Roots of

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FIGURE 6.—Internal cork: A virus disease that develops corklike areas in susceptible varieties at storage temperatures above 60° F.

most other varieties may carry the virus but they do not develop the internal cork symptoms even when stored at temperatures above 60° (*8*, *51*).

Weevil Control

In the few weevil-infested areas where sweetpotatoes are grown, the roots are often dusted or the storage area is sprayed with DDT (*17*, *100*). Sometimes the temperature of the storage is allowed to rise sufficiently to permit the weevil larvae present in the roots to grow and to emerge. The infested roots can then be identified and eliminated during grading. In addition, when the insect emerges, it comes in contact with any DDT on the roots. The DDT-containing dust is washed off during preparation for market. A residue of 7 parts per million is allowed by the Food and Drug Administration.

> ***CAUTION***
>
> Do not feed DDT-treated sweetpotatoes to dairy animals or animals being finished for slaughter. Sweetpotatoes must be washed thoroughly before they are eaten or offered for sale.

PRESPROUTING

Sweetpotatoes saved for seed stock must be in good condition and free of disease. Special production practices are often used to eliminate diseases from seed roots. In addition, these roots should be cured and stored using recommended practices. In the storage house, presprouting—a practice not recommended for roots going to the fresh market—is often applied to seed roots to enable them to produce plants faster when bedded. Presprouting involves the application of curing conditions to cause seed roots to produce sprouts 1 to 2 inches long before bedding (*27*).

Usually presprouting is started about 4 weeks before bedding by raising the temperature of the seed roots to about 85° F. with a high relative humidity and maintaining such conditions until the roots sprout sufficiently. Some ventilation is desirable because the roots respire rapidly when the temperature is raised. Although varieties that are slow to sprout usually require a longer presprouting treatment than others, the treatment is also more beneficial for them. Presprouted roots produce more plants, especially early plants, than roots not presprouted in a given period of time after bedding.

Before bedding, seed roots are often sorted to remove those decayed or off-type. Those remaining are then placed in fairly uniform size categories to aid in uniform plant emergence. Presprouting is often used to heal injuries inflicted during this sorting and handling, since presprouting conditions are the same as those used in curing to heal injuries inflicted during harvesting (*88*, *122*). Bulk-tobacco-curing barns, after some modification, have been used for presprouting (*43*), but most storage houses with adequate curing facilities serve very well.

PHYSIOLOGICAL CHANGES

Some physiological changes take place in roots after they are harvested. Sweetpotatoes are more palatable when held for a few days after harvest before being cooked than when cooked immediately after harvest (*23*, *46*, *53*, *54*, *55*, *56*, *116*, *130*). The major change involves the increase in conversion of starch to sugars and dextrins during cooking. Although the sugar content of the raw roots usually increases some during curing and may increase still more during storage (*49*, *90*, *114*), these changes are small compared with the change of starch to sugars and dextrins that occurs during cooking. Freshly dug roots convert less of their starch to sugar and dextrins during cooking than comparable roots after being cured. Storage for a month or two often increases the conversion of starch to sugars and dextrins during cooking.

Varieties of sweetpotatoes differ in the degree to which they convert starch to sugars and dextrins during cooking. Varieties that tend to convert most of their starch to sugar and dextrins become very sweet and moist; they are referred to as "wet-" or "yam-" type sweetpotatoes. The varieties Porto Rico, Goldrush, and Georgia Red fall into this class. Other varieties, such as Big Stem Jersey and Jersey Orange, convert less of their starch to sugar and dextrins during cooking and are usually somewhat firm and "dry" tasting. Several varieties, such as Nemagold, are intermediate. The classification of varieties into wet or dry types is arbitrary since the classes are not easy to define, and all varieties tend to be more dry at harvest than after curing.

Ascorbic acid content usually decreases some during curing and storage (*38*, *40*, *42*, *117*, *118*).

Some changes in pectin content occur that are associated with the softening of the flesh of cooked roots (*1, 11, 12, 58*). Changes in amide- and amino-nitrogen have been recorded (*50*). Carotene content usually increases during storage (*2, 36, 37, 39, 96*) since the site for synthesis is in the root (*59, 95*).

CONSTRUCTION OF STORAGE HOUSES

General Requirements

The storage house should be designed to provide the temperature, humidity, and ventilation recommended for proper curing and storing of sweetpotatoes throughout the season in the location selected.

Heat is usually necessary in the fall during curing, in the late winter or early spring for presprouting, and often in the winter during the coldest weather. The storage should be designed to provide the amount of heat needed as well as its proper distribution to maintain reasonably uniform temperatures. To do this, heat is usually added beneath the stored sweetpotatoes, since the lower levels of the storage are usually cooler and harder to heat than the top.

Excess heat is removed from the storage house in two ways. Warm air may be exhausted from the top of the storage and cool air introduced through doors and special vents near floor level. Or cool air is introduced into the top of the storage with ventilation equipment or mechanical refrigeration.

High humidities are usually rather easily maintained in most of the sweetpotato-producing areas because the roots give off some moisture and the relative humidity is often fairly high in the outside air. But when large amounts of heat are added to the storage, or in dry climates, some provision for humidifying the air in the storage is needed. Conversely, because outside air temperatures often are considerably lower than the temperature inside the storage room, some provision for removing condensation is desirable. This is usually provided in the system of ventilating that is used both for cooling and for exchange of air.

Locating the storage near the point of production will minimize hauling costs. Size of the storage influences the relative cost per unit stored. Usually large storages are more advantageous than small ones. Large storages often benefit by complementing storage with marketing and processing facilities.

Since all circumstances of weather, construction, or management cannot be anticipated, the following sections will provide some guidelines to consider in constructing and managing storage houses to obtain the objectives. The storage house should be located on a well-drained site with a foundation or footing appropriate to the site and construction of the building. Often the building is designed to include more than storage of sweetpotatoes.

For large storages, or small ones which may be expanded, it is desirable to plan for the following five steps which usually make up the complete operation.

1. Unloading of field trucks directly into the curing room or to the grading equipment (if this is present or to be added in the future).
2. Curing with forklift handling of palletized boxes or provision for it in the future.
3. Storage, either in the curing room or in separate rooms provided for it, also with provision for handling by forklift.
4. Grading, preferably with equipment that includes washing and treating to prevent decay during marketing.
5. Loading trucks (or railcars) for shipment to market.

In large storage houses, office space and restrooms are included, too.

The storage should be located where an adequate supply of electricity and water are available or can be made available. Depending upon the facilities included in the plans, electricity will be needed for lights, conveyors, humidifiers, grading, heating, ventilating, or refrigeration. Special considerations are necessary if the demand for electricity is great; that is, when electricity is used for heating the storage or nearby plant beds. Water is used for humidifying and cleaning the storage, and, usually in large amounts, for washing the roots during preparation for market when this is performed at the storage house.

The exact requirements for operating a storage house will be determined by the size and facilities included. The plans should include provisions for expansion or addition of facilities. For example, a storage house containing 250 tons or more (10,000 bushels) of sweetpotatoes probably will justify pallet and forklift handling, especially if labor costs are high, and the forklift will find use in other activities such as loading and unloading fertilizer. If the forklift is included, the floor, doors, ceiling height, and room dimensions should be suitable for such equipment. In storages of 750 tons or more, the addition of grading equipment is probably justified. Some refrigerated storage space is usually added, especially in the southernmost producing areas in storages above 1,000 tons capacity.

Although earth floors are popular in small buildings because of their low cost and the ease of maintaining high humidity, they are not practical in the larger storages where forklift equipment is used. False floors with underfloor heating work well, but this type of flooring will not support the great weight of forklift equipment.

Since walls and ceiling must withstand moisture, they should be constructed with moisture-resistant materials.

Selection of materials and type of construction will depend upon local availability of materials, cost of materials and labor, and the need for a temporary or a permanent building. Features of wall, ceiling, and floor construction will be considered from the standpoint of heating, cooling, aerating, humidifying, and dehumidifying.

Heating and Cooling Requirements

Heat is needed in a sweetpotato storage house to warm the sweetpotatoes and storage containers to the proper temperature; replace heat lost through walls, ceiling, and floor by direct transmission and radiation; replace heat lost through infiltration of air at cracks around doors, windows, and ventilators; and replace heat absorbed by evaporation of moisture from the roots or storage containers and adhering soil (*13*).

Heat of Respiration

Although some heat is produced by the sweetpotatoes, it is usually insufficient for curing and presprouting, and except in large storages in the southernmost sweetpotato producing areas, for maintaining the storage temperature during the winter. These same factors must also be considered when cooling, since then heat must be removed instead of added.

If essentially sound sweetpotatoes are harvested and placed at 85° F. for curing, respiration will produce about 275 British thermal units (B.t.u.) per 55 pounds of roots (10,000 B.t.u. per ton) for the first day or two. If the roots are placed at a lower temperature after harvest, respiration will be proportionately less by about 22 B.t.u. per day per 55-pound box for each 5° reduction, or about 165 B.t.u. at 60° (6,000 B.t.u. per ton). The rate of respiration, and therefore heat production, varies considerably from one lot of sweetpotatoes to another; consequently these figures must be considered as reasonable approximations only (*69*). Mechanical and physical injuries increase the rate of respiration. Cured roots respire less than freshly dug roots when held at the same temperature and at 60° produce about 100 B.t.u. per 55-pound box, or 3,600 B.t.u. per ton (*68, 69, 108*).

The production of heat by sweetpotatoes damaged by wet or cold soil, chilling during storage, and decay deserves special attention. The respiration rate and heat production of roots damaged by wet or cold soil and chilling is often two to three times greater than for roots not damaged in these ways (*69*). If the damage is great enough, some roots decay, increasing the production of heat still more. The rate of increase depends upon the rapidity and extent of the decay; if decay is extensive, it may be great. Moisture is given off rapidly, too, because of the decomposition of the roots. Extra precautions are usually necessary to provide sufficient ventilation to remove the excess heat and moisture produced.

Vaporization of Moisture and Vapor Barriers

Some evaporation of water from the sweetpotatoes is to be expected. The roots themselves may be carrying moisture or the moisture may be in the soil clinging to the roots or be in the wood of the boxes or pallets. This moisture, along with some produced by the roots, usually evaporates slowly. In calculating heat requirements, the amount of heat absorbed by evaporation or released by condensation is usually disregarded. But during curing, sweetpotatoes usually lose 3 percent or more of their weight, primarily through evaporation of moisture. This evaporation absorbs approximately 60,000 B.t.u. per ton of sweetpotatoes and is approximately the amount of heat produced by respiration during curing. Therefore, in calculating the heating requirements during curing, the heat produced by respiration of healthy roots is not considered nor is heat absorbed by evaporation of moisture, even though respiration may provide slightly more heat than that absorbed by evaporation. During storage moisture evaporates very slowly and loss of heat from this is negligible.

From the standpoint of storage-house construction, vaporization of moisture must be controlled. A good moisture barrier is desirable in the storage to maintain the high humidity recommended, to prevent excessive evaporation, and to prevent excessive accumulation of moisture in the walls. Evaporation of moisture will aid in maintaining the high humidity desired. But at times, especially when large quantities of moisture are carried into the storage house during harvesting from wet soil, moisture levels in the house go above those recommended; that is, above 90 percent, and approach saturation.

When the relative humidity approaches saturation, moisture will begin to condense on any surface that is below the temperature of the air containing the moisture. Usually such condensation occurs in the top of the storage. Warm air, which is capable of holding more moisture than cool air, rises to the top of the room and is cooled slightly by the loss of heat through the walls and ceiling. With the loss of heat, the air deposits moisture on any surface that is cool enough to be at the dew-

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point temperature for the air near it. The amount of condensation is kept to a practical minimum by providing the proper amount of insulation and by removing excess moisture by ventilation.

To avoid undue deterioration in the walls or ceiling, condensation should be prevented within them. This condensation is not as obvious as the condensation on the inside wall surfaces or ceiling; consequently, the deterioration often occurs before the trouble is detected. If a relative humidity of 90 percent is maintained at 85° F. in the storage, the vapor pressure is 0.535 pound per square inch. If the relative humidity outside is 50 percent at 35°, then the vapor pressure there is 0.048 pound per square inch, less than one-tenth that on the inside. Under the influence of this pressure, water vapor will tend to move out through the wall. Often the temperature within the wall is below the dewpoint temperature of the air in the room and moisture will condense within the wall (or ceiling).

A moisture barrier retards movement of water vapor. As long as the vapor can move out of the "cold" side of the wall faster than it moves in from the "warm" side, little trouble is experienced. Insufficient data are available from sweetpotato storage studies to recommend the degree of resistance to moisture movement to provide in the vapor barrier, but recommendations for similar structures have proved useful (*16*). Sheet-type vapor barriers, such as polyethylene sheets, 2 to 6 mil thick, are often used for this purpose in the coldest parts of the sweetpotato-producing areas. When these sheets are used, they should be applied carefully to prevent damaging them. Asphalt or oil varnish paints are useful vapor barriers if two or more coats are applied. Other paints such as aluminum and alkyd gloss are also effective.

Shiny-surface roll roofing, heavily asphalted building felt with a shiny surface, and duplex-kraft paper with aluminum foil on one side or with asphalt between laminations are effective moisture barriers and are necessary in a frame wall filled with insulation.

Board-form insulation having an asphalt coating is preferable to the uncoated type for vapor-proofing. The joints between the insulation panels should be filled with a waterproof compound and the entire surface mopped heavily with two coats of hot asphalt or painted with two coats of asphalt-base aluminum paint. Concrete- or cinder-block walls may be made vapor-resistant by painting the interior surface with a cement-water wash. When this is thoroughly dry, two coats of asphalt-base aluminium paint should be applied. Specific details for installing commercial insulation and vapor barriers are usually available in the directions given by manufacturers.

The exterior walls of the storage house should be constructed or treated in some way to prevent entrance of moisture into the insulation from driving rain or snow. An overhanging roof is very helpful. Two coats of cement-water paint should be thoroughly scrubbed into the pores of concrete- and cinder-block walls.

Ventilating a wall or ceiling cavity is effective in controlling condensation. Unvented insulation in the ceiling is particularly troublesome since the insulating value of any material is reduced by the accumulation of moisture. This trapped moisture in turn causes portions of wooden joists and the ceiling to decay rapidly. No vapor barrier completely prevents moisture from moving through the walls or ceiling. Construction then should provide some ventilation to remove this moisture. In frame walls, small openings may be made toward the outside at the top and bottom of the stud spaces to permit moisture to escape, or holes may be bored through the plate, sill, or cornice.

On unvented insulated walls under extreme conditions, as found in farm structures used for sweetpotato storage, an 8-1 perm ratio of outside to inside wall covering is necessary. This limits sheathing moisture to 20 percent (dry basis), which is the maximum desirable to prevent decay in wood members. A perm ratio of 3–1 or greater is needed to prevent the formation of free moisture within insulated walls. One perm equals the transmission of 1 grain of water per hour per square foot per inch of mercury vapor pressure.

In view of the problems often encountered with moisture in sweetpotato storage structures, recent trends have been toward masonry construction, even in the ceiling. Fire insurance rates are usually considerably lower also where wood and other flammable materials are eliminated or nearly eliminated.

Product Load

Sweetpotatoes delivered to the storage house for curing and storing usually arrive at a temperature near that of outside air. Early in the harvest season this may be near the 85° F. temperature recommended for curing, whereas late in the season on cold days the temperature occasionally may be as low as 40° or 45°. The amount of heat required to warm the sweetpotatoes to the recommended 85° will vary according to their temperature on arrival and the quantity delivered. Generally, enough heat should be provided in the storage house to raise the temperature of the sweetpotatoes to 85° within 24 hours so that the roots brought in each day will reach curing temperature before more are placed in the curing room.

Certain assumptions are needed to design a storage that will meet most situations arising during the season. The first assumption is that the sweetpotatoes usually will not be chilled in the field or by delayed delivery to the storage house. Therefore, they will arrive at temperatures no lower than 55° F. most of the time; that is, no more than 30° below the recommended 85°. A second assumption is that the sweetpotatoes will be handled in field boxes containing from 50 to 55 pounds of sweetpotatoes, so we may accept 55 pounds as a working figure. Furthermore, the empty boxes will weigh approximately 4 pounds each, soil and moisture adhering to the roots and in the box is negligible (that is, 0.1 to 0.2 pound) and the roots will not be excessively damaged by harvesting or by wet or cold soil.

With these assumptions, it is possible to calculate the amount of heat needed to bring the sweetpotatoes to 85° F. for proper curing, if heat produced by respiration and lost by evaporation of moisture is disregarded (p. 13).

To warm 55 pounds of sweetpotatoes 30° (from 55° to 85° F.) requires about 1,320 B.t.u.; that is, 30 times 55 times 0.8, where 0.8 is the specific heat of the sweetpotatoes at 75 percent moisture content. To warm a 4-pound wooden box 30° requires about 48 B.t.u.; that is, 30 times 4 times 0.4, where 0.4 is the specific heat of the wood. Similar calculations may be made if it is assumed that sweetpotatoes will arrive at the storage at some temperature other than 55°. For the practical purpose of storage-house design, it is probably safe to assume that not over 1,300 B.t.u. will be required to raise the temperature of one box of sweetpotatoes (55 pounds) to 85° throughout most of the harvest period. During warm weather no additional heat may be required (*61*). If the rate of filling the house is known and losses of heat through walls, ceilings, and floors and by infiltration are estimated, the total heat requirement may be calculated.

Approximately the same calculations may be used to determine the heat required to raise the temperature of stored roots to presprouting conditions. Because presprouting is usually done during February or March, a room with the smallest outside wall area is often used.

Loss of Heat Through Walls, Ceilings, and Floors

Loss of heat through walls and ceilings depends primarily upon the amount of resistance provided to the movement of heat through the materials used in the walls or ceiling. The insulating value of construction materials is rated by a factor k, defined as the rate of heat transfer in B.t.u. per hour through a 1-square-foot area of 1-inch thickness per unit of temperature difference between the outside and inside surface. This factor is often difficult to use for combinations of construction materials and a simpler method rates insulation in thermal resistance. Thermal resistance (R) is related to k, according to the equation $R=\frac{1}{k}$. If the resistance values of different materials in a wall or roof are known, they may be added together to give the total resistance to movement of heat. Representative R values for some commonly used construction materials are given in table 1, along with commonly accepted values for air films that provide some resistance to heat loss, too.

TABLE 1.—*Thermal resistance of building materials frequently used in construction of sweetpotato storage houses*

Material and description	Thickness	Resistance [1]
	Inches	*R*
Air space:		
Dead air space in wall	¾–4	0.97
Dead air space in ceiling	¾–4	.85
Air surface:		
Outside air film (15½ m.p.h.)		.17
Inside air film (still)		.68
Board:		
Asbestos-cement board	⅛	.03
Plywood	¼	.31
Do	⅜	.47
Do	½	.63
Wood sheathing	25/32	.98
Asphalt impregnated sheathing	½	1.32
Do	25/32	2.06
Building paper:		
Felt, 15-pound grade		.06
Felt, 30-pound grade		.12
Masonry:		
Brick, common	4	.80
Brick, face	4	.44
Concrete block, 3 core	4	.71
Do	8	1.11
Do	12	1.28
Lightweight aggregate block	4	1.50
Do	8	2.00
Do	12	2.27
Lightweight aggregate block, core filled with granulated insulation	8	[2] 5.88
Do	12	[2] 6.67
Siding:		
Asphalt roll		.15
Asphalt insulating siding	½	1.45
Wood		.80
Roofing:		
Asbestos-cement shingles		.21
Asphalt-roll		.15
Asphalt shingles		.44
Wood shingles		.94
Insulation:		
Mineral or rock wool	1	3.70
Plastic (foamed) polystyrene	1	3.45
Corkboard	1	3.70
Cement and granular insulation (1:4)	2	[3] 4.07
Do	4	[3] 6.45

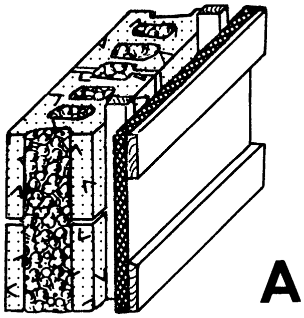
[1] Abstracted from *Heating Ventilating and Air Conditioning Guide* (1958) Ch. 9, except as indicated.

[2] Concrete Masonry Manual, N.C. Concrete Masonry Association, Raleigh, N.C., April 1964.

[3] Specifications and Data Perlite Insulating Concrete Over Metal Form Units, Perlite Institute, Inc., International Association of Perlite Miners and Processors, May 1962.

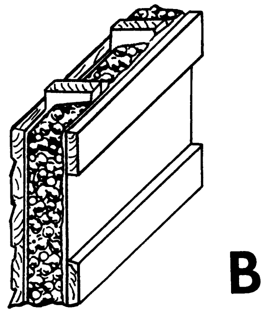
Representative wall and ceiling construction is given in figure 7.

Masonry walls can be insulated in several ways. Lighweight aggregate or cinder block or structural-clay tile cores can be filled with a pellet or granular type of insulation (expanded mica). This type of insulation is easily added as the wall is built and is generally less expensive than other types. In this connection, 12-inch blocks may be used to build walls in most areas to a height of 20 feet without pilasters or other support for the walls except where girders or trusses are to be



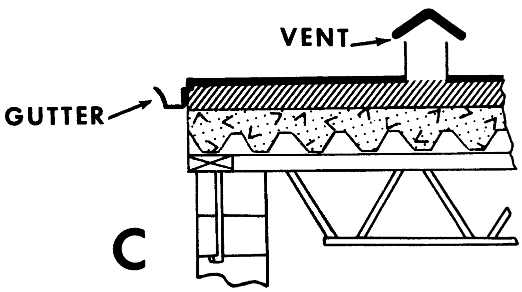
OUTSIDE AIR FILM—0.17
12" BLOCK, GRANULAR FILL—6.67
DEAD AIR SPACE, 2"—0.97
½" ASPHALT IMPREGNATED SHEATHING—1.32
WOOD STRIPS, 1"×4"—0.20
INSIDE AIR FILM—0.68

TOTAL THERMAL RESISTANCE--10.01



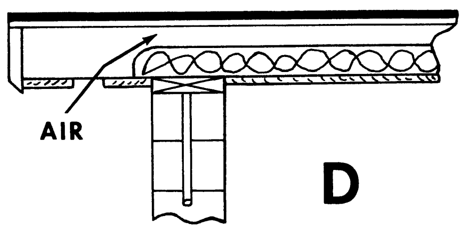
OUTSIDE AIR FILM—0.17
WOOD SIDING—0.80
ROCK WOOL BATT, 3"—11.10
ASPHALT ROLL SIDING—0.15
WOOD STRIPS, 1"×4"—0.20
INSIDE AIR FILM—0.68

TOTAL THERMAL RESISTANCE--13.10



OUTSIDE AIR FILM—0.17
4-PLY BUILT-UP ROOF—1.08
1½" RIGID INSULATION BOARD—4.19
4" PERLITE-CEMENT MIX—6.45
CORRUGATED SHEET IRON—0.05
INSIDE AIR FILM—0.68

TOTAL THERMAL RESISTANCE--12.62



OUTSIDE AIR FILM—0.17
4-PLY BUILT UP ROOF—1.08
ROOFING BOARDS, 25/32"—0.98
4" ROCK WOOL BETWEEN JOISTS—14.80
4 mil POLYETHYLENE—0.10
¼" EXTERIOR PLYWOOD—0.31
INSIDE AIR FILM—0.68

TOTAL THERMAL RESISTANCE--18.12

Figure 7.—Wall and roof details showing relation of construction to thermal resistance.

used to support the roof. Local or other applicable codes should be followed in determining the need for pilasters or other supports. An 18- to 20-foot height is high enough for most palletized operations if proper clearance is maintained.

If the granular-fill type of insulation is not desired, insulation board attached to 2- by 2-inch or 2- by 4-inch vertical furring strips is often used. Strips 1 by 3 inches or 1 by 4 inches spaced about a foot apart should be nailed over the insulation board so that holes will not be punched in it. A moisture-resistance finish may be applied to seal nailhead and other holes.

Masonry walls, usually cinder or concrete blocks, are relatively windtight and watertight, permanent, and low in upkeep. Asbestos-cement boards are not affected by moisture or decay, are fire- and vermin-resistant, do not require painting, and are reasonably strong when properly supported. Galvanized-sheet steel is relatively low in first cost, is easy to apply, and has advantages similar to those of asbestos-cement boards. Aluminum sheets are also satisfactory as interior lining or exterior finish, but should not be used in contact with earth, concrete, mortar, or other metals unless protected with asphalt paint. Aluminum nails should be used for applying sheets. Moisture-proof plywood, laminated asphalt-felt board, and emulsified-asphalt gypsum board are suitable materials when properly installed. All commercial materials should be installed according to the recommendations of the manufacturers.

A wood interior lining has a reasonably long life if the walls and ceilings are properly insulated so that little condensation occurs. The wood can be protected by covering it with a vaporproof membrane and fastening the lining down tightly with closely spaced lath or other wood strips.

Fortunately, the amount of thermal resistance needed to prevent excessive consumption of fuel corresponds fairly well with the amount of thermal resistance needed to maintain the high relative humidity recommended. The inner surface of a wall or ceiling cools as heat is transmitted through it. Rapid loss of heat will mean that the inside surface will cool more than if heat is lost slowly. Therefore, the insulation properties determine the temperature on the inside surface which, in turn, determines whether moisture condenses on this surface because the dewpoint temperature is reached.

Figure 8 shows the theoretical outside temperature at which condensation will begin in a storage house with walls of a given conductance when the inside relative humidity is held at a given point for both the curing temperature of 85° F. and the storing temperature of 55° (*15*).[3]

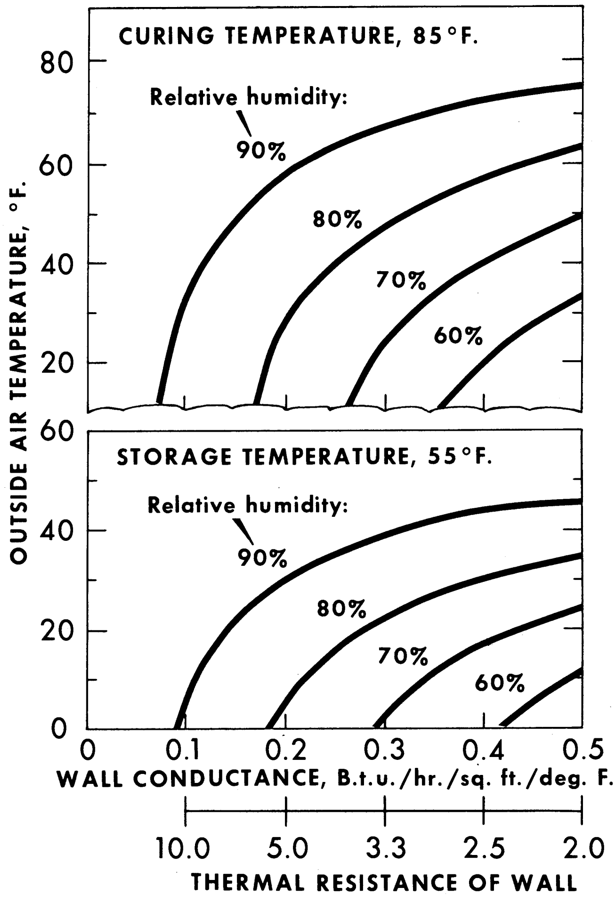


FIGURE 8.—Theoretical condensation conditions during curing at 85° F. or storage at 55°.

For example, a wall with a thermal resistance of 5.0 should conduct 0.2 of a B.t.u. through each square foot of wall surface in 1 hour for each degree Fahrenheit difference in temperature between the room and outside air; that is, 6 B.t.u. per hour per square foot for a 30-degree difference. Also, this same wall should permit condensation on its inner surface if the temperature in the room is 55° F. and if (a) the outside air temperature is 30° and the relative humidity in the room exceeds 90 percent, or (b) the relative humidity in the room is 90 percent and the outside air temperature drops below 30°.

From figure 8, then, it can be determined how much insulation is needed to permit the maintenance of the high relative humidity recommended if the outside air temperature is known. Or, to summarize, the following combinations of outside air temperature and insulation permit the maintenance of 90-percent relative humidity at 85° or 55° F.

[3] Presumably from equation $T_s{-}T_1{-}\frac{U}{f_i}(T_1{-}T_o)$ (*44*).

Outside temperature (°F.)	*Thermal resistance value of wall for—*	
	85°	*55°*
70	3.1	------------
60	5.2	------------
50	7.3	------------
40	9.3	3.5
30	11.4	5.9
20	13.5	8.3
10	15.7	10.6
0	17.6	13.0

Therefore, a wall with a resistance value of 11.4 would permit the outside air temperature to drop as low as 30° during curing at 85°, or to 10° during storage at 55°, before condensation would occur if the relative humidity was 90 percent or lower in the storage house.

Each of the combinations of outside air temperature, wall insulation (thermal resistance), and 90-percent relative humidity will allow about 5 to 5½ B.t.u. heat loss per square foot per hour. If the thermal resistance of the ceiling is 1½ times greater than in the walls, about 3½ B.t.u. heat loss will occur per square foot per hour for these combinations. If, then, thermal resistance is provided as indicated to maintain the proper relative humidity during the coldest weather expected, the maximum loss of heat will be within reasonable limits, and an estimate of the rate of maximum heat loss through walls and ceiling obtained:

Wall area (in square feet) times 5 plus ceiling area (in square feet) times 3½=B.t.u. per hr. loss at the outside air temperatures that will cause condensation to begin to form if the relative humidity inside is 90 percent. This calculation assumes that all walls are outside walls, but this is seldom true.

Since harvesting continues in all producing areas up to and often after frost kills the leaves and vines of the sweetpotato plant, it is apparent that conditions of 85° F. and 90-percent relative humidity inside and about 30°, 35°, or 40° outside exist part of the time. However, such low temperatures outside exist for only a short time, and an average temperature over several hours, or even a day, is more useful in estimating requirements. During storage the maximum insulating requirements may be estimated from the average annual minimum temperature in the area (fig. 9).

This temperature will vary in different parts of the country. To reach a compromise between requirements at harvest for curing and during the winter for storage, the following thermal resist-

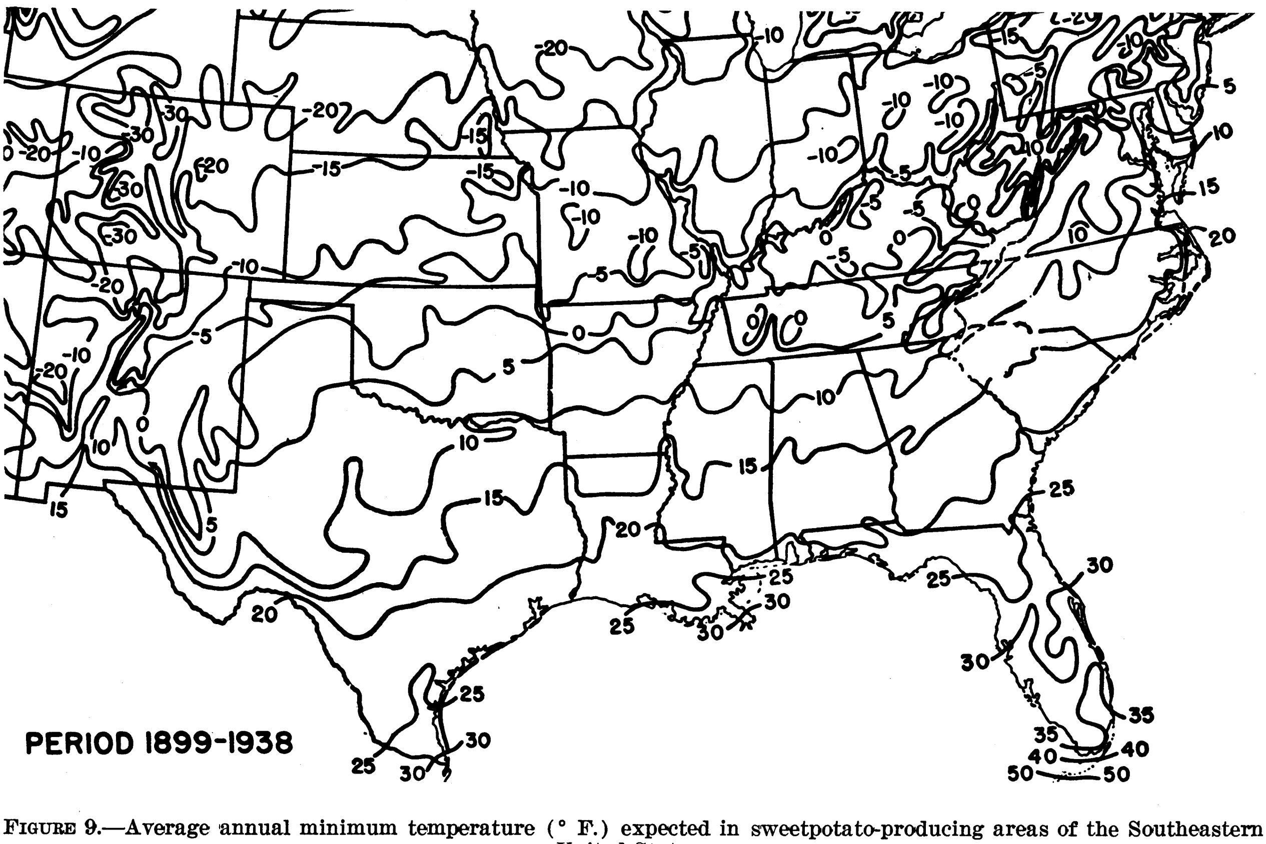


FIGURE 9.—Average annual minimum temperature (° F.) expected in sweetpotato-producing areas of the Southeastern United States.

ances are suggested for areas where the average annual minimum temperature is as indicated:

Average annual minimum temperature ° F.	*Thermal resistance* (R) *Wall*	*Ceiling*
0	10–13	15–20
10	8–10	12–15
20	6–8	9–12
30	4–6	6–9

The roof or ceiling should be better insulated than the walls so that any condensation will occur first on the walls where it cannot drop on the sweetpotatoes. In general, a factor of at least 1.5 times as much insulation should be provided in the ceiling as in the walls of the same room. If fuel is relatively expensive, the higher thermal resistance values should be considered for the appropriate average annual minimum temperatures. Interior walls may require less insulation than exterior walls since the temperature in adjoining rooms is usually no lower than 55° F. Rooms used only for storage after curing in another room require less insulation than curing or presprouting rooms.

Loss of heat through the floor is usually of little consequence since part of it is radiated back to the room. Loss around the periphery of the room may be estimated by multiplying the linear feet of outside wall by 14 to obtain the B.t.u. loss per hour (*13*).

Heat requirements should be calculated for a proposed storage house based upon the construction details and the way the storage house is to be operated, as well as the expected weather in the area of construction (*13*). An allowance for the inefficiency of the heating system usually is included also. This inefficiency may amount to 25 to 50 percent of the calculated requirements. An estimation can be obtained as follows:

Given a room 22 by 50 by 18 feet high with a thermal resistance of 5 in the walls and 7.5 in the ceiling, a capacity of 5,000 55-pound boxes to be put in at a rate of 1,000 per day, and an outside temperatures that will average no less than 55 ° F. during a 24-hour period at harvest and develop an outside annual mean minimum of 20°; then estimated maximum heat requirements per hour are:

A. For curing

	B.t.u./hr.
No. 55-lb. boxes/day × 55 [1] (product load) or (1,000 × 55)	55, 000
Walls (sq. ft.) × degree [2] × B.t.u./sq. ft./hr./degree [3] or (2,592 × 30 × 0.2)	15, 552
Ceiling (sq. ft.) × degree [2] × B.t.u./sq. ft./hr./degree [3] or (1,000 × 30 × 0.13)	3, 900
Perimeter (linear ft.) × 14 or (144 × 14)	2, 016
Total	76, 468
Plus infiltration (10 pct.) [4]	7, 647
Grand total	84, 115

B. Storage

	B.t.u./hr.
Walls (sq. ft.) × degree [5] × B.t.u./sq. ft./hr./degree [3] or (2,592 × 35 × 0.2)	18, 144
Ceiling (sq. ft.) × degree [5] × B.t.u./sq. ft./hr./degree [3] or (1,100 × 35 × 0.13)	5, 005
Perimeter (linear ft.) × 14 or (144 × 14)	2, 016
Total	25, 165
Plus infiltration (10 pct.) [4]	2, 517
Grand total	27, 682
Less No. 55-lb. boxes × 4 [6] (5,000 × 4)	20, 000
Net total	7, 682

[1] 1,320 divided by 24, assuming heat produced by respiration equals heat lost by evaporation.

[2] 85° F. inside less 55° outside.

[3] From figure 8, or $\frac{1}{R}$.

[4] See discussion on p. 20.

[5] 55 less average annual minimum temperature from figure 9.

[6] 100 B.t.u./24 hours divided by 24 (heat of respiration at 60° F.).

The heat produced by respiration enters the problem of storage-house design and management in another way. As the capacity of storage rooms increases, the wall and ceiling areas increase but not as rapidly as the room capacity. This influences the rate at which heat produced by respiration is lost. For example, a room measuring 24 by 40 and 18 feet high is capable of holding about 5,400 boxes of sweetpotatoes (30 boxes per pallet and pallets 6 by 10 and 3 layers high). If the walls have a thermal resistance of 5 and the ceiling 7.5, a loss of about 17,500 B.t.u. will occur each day for each degree the outside temperature is below that inside the room (table 2). The sweetpotatoes, at 60° F., will produce about 540,000 B.t.u. per day or enough to compensate for heat lost through the walls and ceiling at an outside temperature of about 29°. A smaller room provides less and a larger room more protection as long as the rooms are well filled.

Obviously, this is an ideal illustration and under commercial conditions the situation may be considerably different. All walls were assumed to be outside walls, which is frequently not true. Furthermore, infiltration may be greater than the 10 percent allowed or decay may add more heat than calculated as heat of respiration. The room may not be full. The temperature of the sweetpotatoes will probably not be exactly 60° F. and, of course, more heat will be produced above 60° than below. Evaporation of moisture will probably consume some heat.

Despite all the variables involved, the example illustrates that the mass of sweetpotatoes in storage may be large enough so that little or no additional heat will be required during the winter. This would depend, of course, on adequate insulation in the storage house and proper distribution

TABLE 2.—*Relation of size of storage rooms to calculated heat requirements* [1]

Heat losses (per °F. per day)	Room dimensions (feet)[2]		
	12 × 24	24 × 40	40 × 48
	B.t.u.	*B.t.u.*	*B.t.u.*
Walls (R=5)	5, 216	11, 059	15, 216
Ceiling (R=7.5)	888	2, 995	5, 976
Perimeter (ft.×14)	1, 008	1, 792	2, 464
Infiltration (10 percent)	711	1, 680	2, 366
A. Total heat loss/°F./day	7, 823	17, 526	26, 022
B. Heat of respiration at 60 °F., boxes × 100=B.t.u./day	162, 000	540, 000	1, 440, 000
	°F.	*°F.*	*°F.*
C. Protection from heat of respiration	21	31	55
D. Outside air temperature to which protected	39	29	5

[1] Assuming all walls are exterior walls and rooms are filled with palletized boxes containing 55 pounds each, 30 boxes per pallet, pallets 3 layers high; that is, 90 boxes per 4- × 4-foot floor area.
[2] All rooms 18 feet high.

of the heat produced by the sweetpotatoes. Unfortunately, this last requirement is not easily obtained unless air circulation is provided, since heat tends to collect at the top of the storage rooms.

Infiltration

The amount of infiltration of air through openings, such as cracks, open doorways, around ventilators, is difficult to estimate. Usually, about 10 percent of the heat required to bring the sweetpotatoes to the proper temperature or replace heat lost through the walls, ceiling, and floor is assumed to be lost by infiltration. If it is assumed that infiltration will be equivalent to one air change per hour (*13*), an estimate can be obtained from the equation

$$\text{B.t.u./hr.}=0.018\, Q\ (T_i-T_o),$$

where Q is the capacity of the room in cubic feet, and T_i and T_o are the inside (room) and outside air temperatures, respectively. This will provide an estimate closer to 15 percent of the heat requirement to raise the product temperature and to replace heat lost through walls and ceiling. If the storage is not well constructed or managed, this value of infiltration may be more realistic than 10 percent. These rates of infiltration provide sufficient air exchange to prevent accumulation of carbon dioxide or depletion of oxygen under most circumstances (p. 13).

Heat Distribution and Source

After certain assumptions have been established for the construction of the storage house regarding its size and general management and expected weather conditions, the heat requirements may be estimated. In general, selecting a heating system with sufficient capacity for the job is no problem; but often one or two factors are overlooked in the design of the storage that affect proper distribution of the heat.

When possible, the heat should be placed under the sweetpotatoes; even then heat will rise either through or around the stacks. After the proper temperature is reached for curing or presprouting, some circulation of air is often desirable to prevent heat from accumulating at the top of the room, especially if the sweetpotatoes are stacked 10 feet or more high. Second, it is not uncommon for some of the sweetpotatoes near the heating element to become overheated, resulting in the temperature of a few boxes of roots to rise over 95° F. As a result, these roots do not heal properly, or even worse, the temperature near them may soar over 110° for several hours, causing the roots to decompose.

Heat is easily distributed with electric-strip heaters placed under a false floor in a pattern that provides slightly more heat near outside walls than near the center of the room (*30*, *32*, *121*). The cost of this equipment is not high and thermostatic control reduces labor cost. Baffles are placed over the heaters to prevent overheating potatoes directly over them and to reduce fire hazard. A 1,000-watt (1 kw.) heater will produce about 3,400 B.t.u. per hour.

Where earth or false-floor construction is used, the storage containers should be at least one foot above the ground to permit free circulation of air. Sills or other wooden parts near the ground should be treated with a preservative to prevent them from decaying. A slatted floor made of 1-by-4's spaced ¾-inch apart is necessary to permit air circulation. A false floor should be made in movable sections to permit cleaning and repairs underneath and with joists capable of supporting the stack of sweetpotatoes.

In areas where power rates are relatively high, heating with electricity may not be economical. In addition, because of seasonal use of electricity and the necessity of some companies to provide heavy duty service at times, power companies make demand charges. These charges may be reduced by use of a seasonal rider offered by some companies or by operating selected circuits rather than all circuits at one time. Records for small, well-built houses in the Southeastern States show that sweetpotatoes can be cured and stored for several months with an electric-energy consumption of not over 4 kilowatt-hours per 55-pound box. All electric installations should be in accord with the rules of the National Board of Fire Underwriters.

Gas- and oil-fired furnaces or burners, vented to the outside and with proper safety controls and fans are widely used for heating sweetpotato houses. In small storage houses the heat may be released under floor racks or false floors. Ducts placed in or, if necessary, on concrete floors are used to release air through registers at appropriate locations about the room. The number and size of ducts should be determined by the heating contractor to supply not over 5,000 B.t.u. per hour to each register (fig. 10, *A*).

Too often, though, to keep costs down, too few registers are provided and the roots near the registers have been damaged. Once registers are installed, it is difficult to change their position. When sufficient registers are properly distributed floor ducts work well. Circumstances and register requirements vary, but needs can be estimated as follows:

Allow approximately 1.5 square feet of register and 450 cubic feet per minute (c.f.m.) air movement for each 1,000 55-pound boxes in storage. For each 250 to 300 boxes, ⅓ to ½ square foot of register is desirable. With proper distribution of registers, heated air leaving the furnace may be 120° to 130° F. and 95° to 100° at the registers to deliver about 5,000 B.t.u. per hour per register. When the heated air is allowed to spread under a false floor or palletized boxes, roots near the register seldom become overheated.

Registers in the floor or ducts on the floor create problems with forklift operations. Even if the registers are only 4 inches across, they become uneven and cause the forklift to shake noticeably when going over them. A system of trench distribution of heat was developed for use with forklift handling. Trenches should be made to support no less than 2½ times the weight of the rated capacity of the forklift, since the weight of the fork and the fork load will be borne primarily by the front wheels of the fork. A span of 12 inches, with load-bearing trench shoulders of 4 inches on each side of the span, works well with forks rated at 1 to 2 tons when 2- by 6-, 2- by 8-, or 2- by 10-inch hardwood free of knots and with 8 percent or less slope in the grain is used. Depth of the trench is optional as long as it will handle the air from the furnace (fig. 10, *B*).

A trench level with the concrete floor is highly desirable and is usually attained if finished lumber is used for forms and for covering the finished trench. A trench 12 inches wide and 12 inches deep can handle large quantities of heated air, or electric-strip heaters.

If electric-strip heaters are used, the boards over the trench, which are usually fastened together in sections with 2- by 4-inch stringers, may be spaced about 1 inch apart on all trenches. If warm air is forced through the trenches, the boards over the trenches should be placed alongside one another over approximately one-fourth of the total trench area next to the source of heat. The boards should be spaced approximately ¼ inch apart over the next section of trench, then ½ inch, and finally 1 inch apart at the farthest distance from the source of heat. Because the heated air is warmest near the furnace and because the boards do not fit perfectly (usually after some shrinkage), sufficient heat will reach the roots in the area where the boards have been placed alongside one another. Adjustments, however, are easily made if needed.

After the proper temperature of the storage house has been reached, during curing and presprouting, the furnace fan should be operated intermittently or continuously to prevent stratification.

Trenches are spaced every 8 to 10 feet apart (figs. 11 and 12). Where pallets are used in the storage, a trench should be provided for each two rows of pallets—that is, for 44- by 44-inch pallets, trenches should be 8 feet apart (on centers) to allow room for two pallets and a few inches of clearance in stacking and unstacking as well as sufficient air movement. This will also avoid stacking crates against walls.

A thermostat should be used to control the heating equipment. The thermostat, or its sensing element, should be mounted near the top of the stacked sweetpotatoes but not less than 1 foot below the ceiling (fig. 10, *C*). The controls should be accessible from the doorway into the room. Sensing elements on long capillary tubes may be placed where the thermostats are shown and the controls placed in a more accessible position. However, the sensing elements should not be placed next to a wall or where infiltration will affect them.

When heat is introduced and properly distributed at the bottom of the room under the stored sweetpotatoes, it will rise slowly and warm the

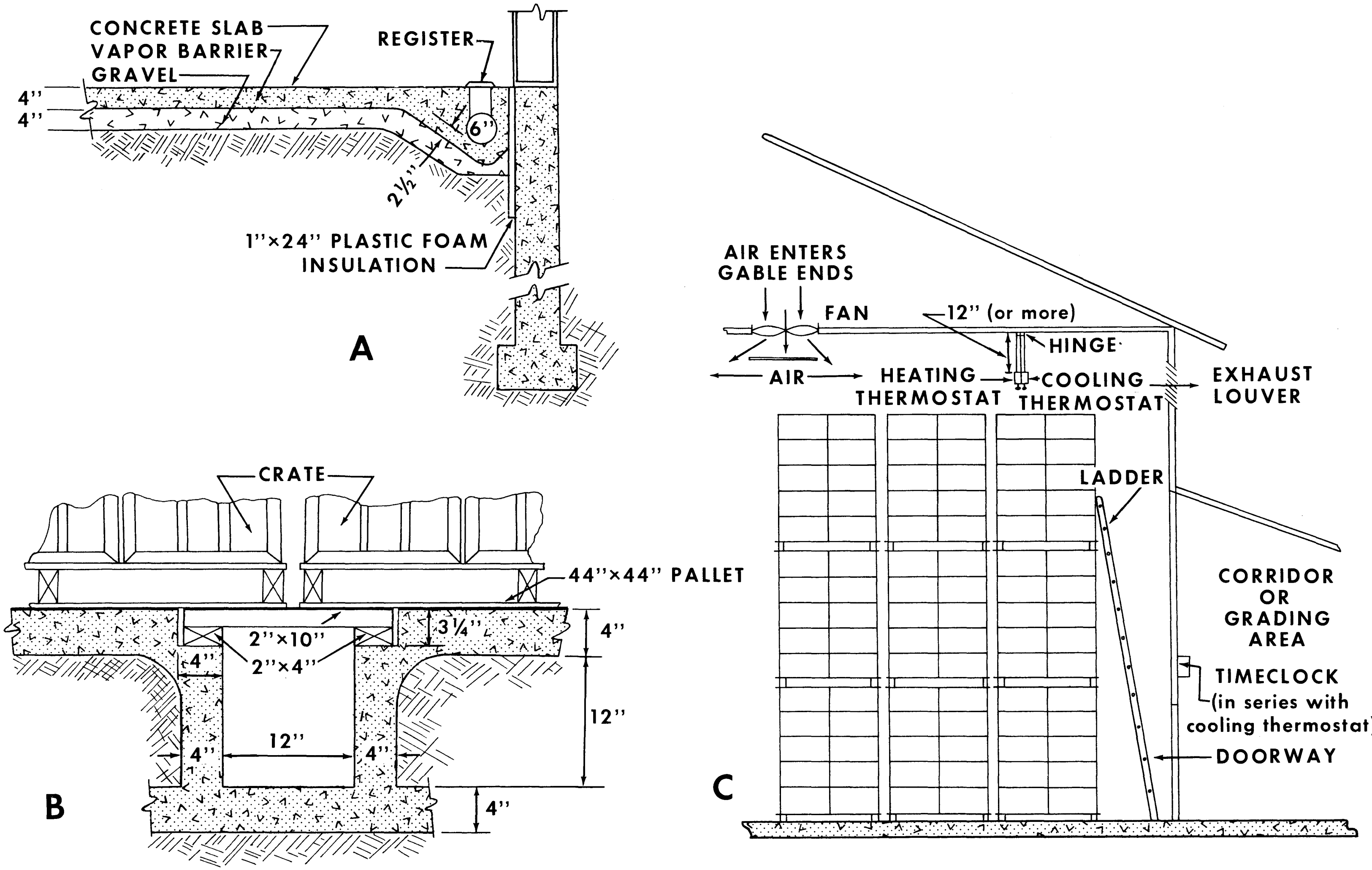


FIGURE 10.—Suggested construction details for heating system: *A*, Location of ducts in concrete floor; *B*, trench detail; *C*, location of thermostat.

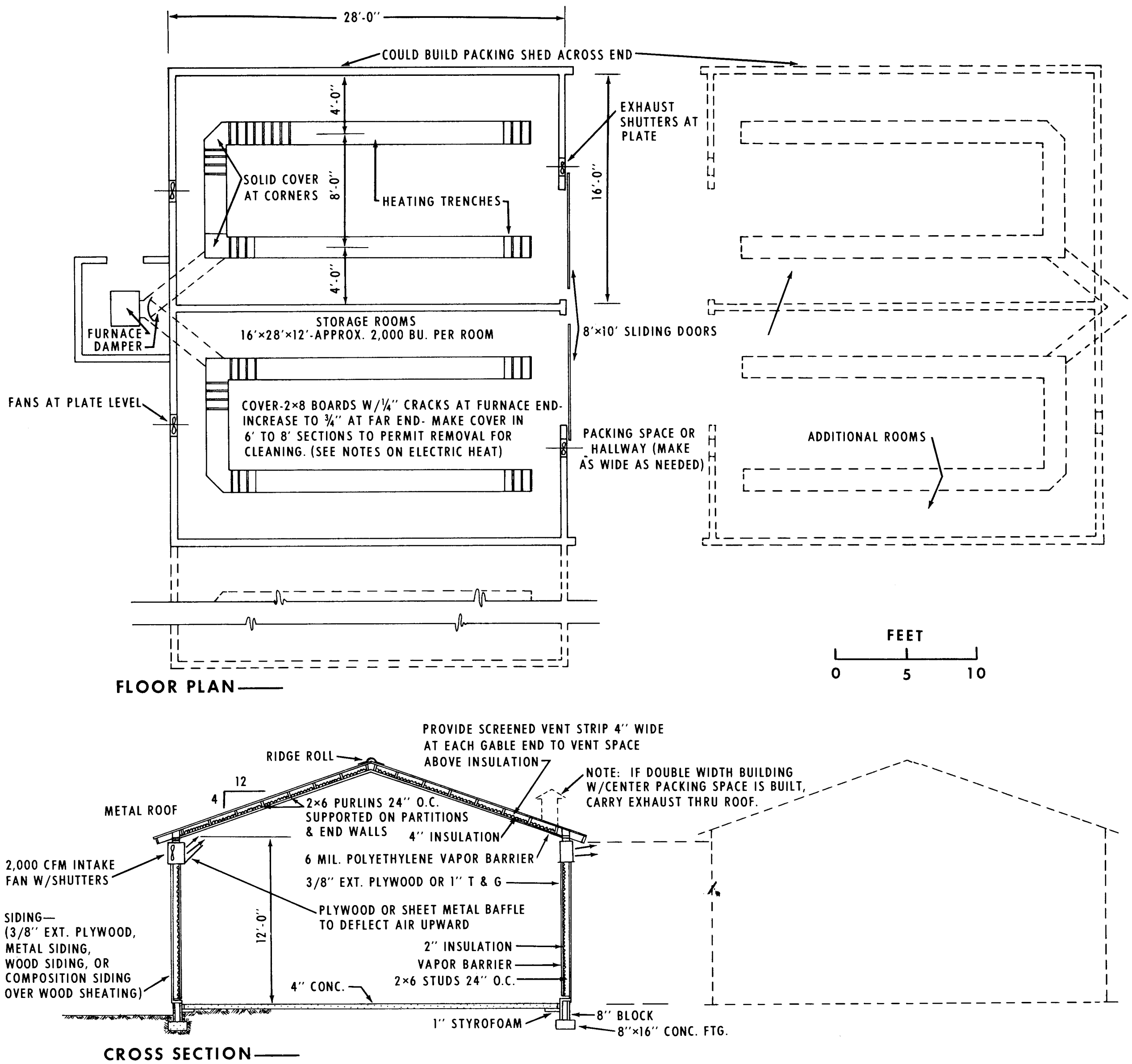


FIGURE 11.—Schematic floor plan for a storage composed of several rooms. Room size may be changed to meet needs, but four or more rooms are recommended for this type of storage. (Courtesy R. Ritchie, Dept. Biol. and Agr. Engin., N.C. State Univ.)

entire stack. Thermostatic control of the temperature near the top of the room provides for reasonably uniform heating, prevents overheating at the top, and permits coordinating the heating system with a ventilating system.

The heated air may be blown into the top of the storage room from heaters mounted or ducted near ceiling level, but this is not recommended. Roots in the top of such rooms are often 10° to 20° warmer than those near the floor, and excessive sprouting of roots near the ceiling is common.

Removal of Heat

After curing, the temperature should be lowered to 55° or 60° F. as soon as possible. A period of 7 to 10 days usually is allowed for this but it should be done in 2 or 3 days if possible. Cooling is usually accomplished with ventilation, but it may be done with mechanical refrigeration. Ventilation is the more popular method, since outside air temperatures at night are usually low enough during the last part of the harvest period to permit efficient cooling.

Ventilation

Convection and overhead ventilating systems are used. In convection-type ventilation, cool air enters the storage through doors or specially constructed vents located on outside walls near the

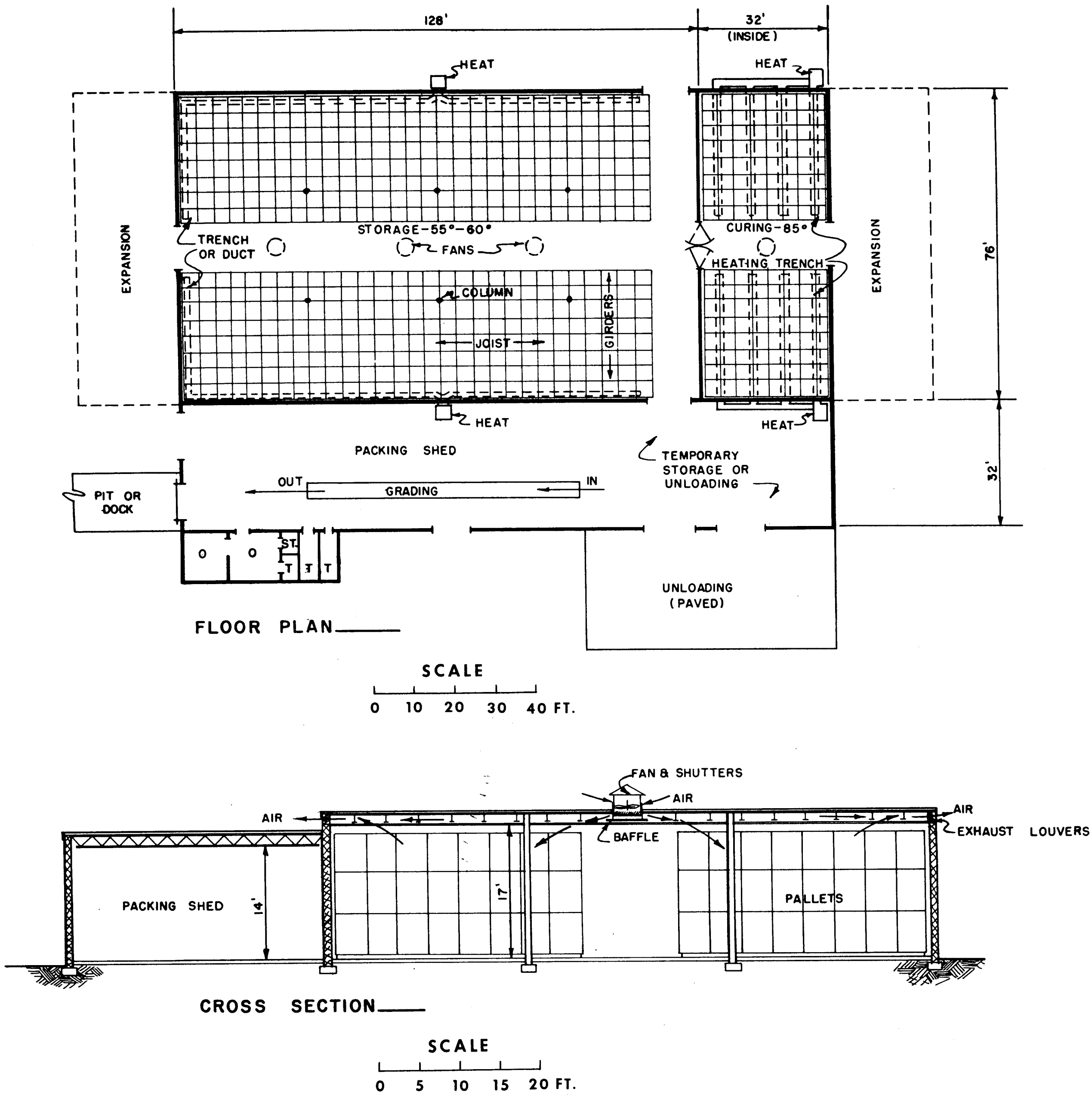


FIGURE 12.—Schematic floor plan for a storage composed of a curing room (or rooms) and a separate storage area. This system is recommended only for storages which are equipped to handle palletized field crates (or bulk bins). The sweetpotatoes are moved carefully with a forklift to the storage room after they are cured. (Courtesy R. Ritchie, Dept. Biol. and Agr. Engin., N.C. State Univ.)

ground (fig. 13, *A*) and warm air is exhausted at the top of the building (fig. 13, *B*).

The removal of warm air from the top of the storage may be increased with an electric fan or blower, controlled by a refrigeration-type (cooling) thermostat with contact closure on temperature rise. This system brings cool air into the bottom of the storage where the sweetpotatoes are usually a few degrees cooler than those in the top of the room. It is not uncommon for the sweetpotatoes at the bottom to become too cool while those at the top are still too warm. During the winter, chilling often occurs around intake vents near the bottom of the storage, even when these vents are tightly closed.

In general, for convection-type ventilation the area of intake and outtake ventilators should each equal approximately 1 percent of the floor area. More than this may be needed in the southernmost areas and less in the northernmost areas of production. Some insulation is usually needed to prevent condensation on the dampers and vent covers during cold weather. Screens should be used on intake vents or doorways to prevent rodents from entering.

The overhead ventilation system uses a blower to move cool air into the top of the storage (figs. 10, *C* and 13, *C*) so as to form a layer of cool air across the top of the room (*73*). In figure 13, *C*, details are given for hood and baffle for an intake blower mounted in the roof of a storage room. Areas of air movement (*A* and *B*) should equal or exceed 1½ times the area of the fan orifice, and the baffle-board dimensions (*C*) should equal or exceed 1½ times the fan diameter. The shutter is spring-loaded and opens with the pressure of the fan. In some instances, two sides of the opening (*B*) may be enclosed and the other two closed with a lightweight plastic damper to reduce condensation on the fan. The hardware cloth shown prevents entry of birds.

The air passing over the sweetpotatoes is allowed to pass through pressure-operated louvers to the outside at the top of outside walls (fig. 13, *D*). In mild climates the door shown in figure 13, *D* can be eliminated and the louver mounted on the exterior of the wall. The door, however, if one is used, must be propped or fastened open when the blower system is operating.

With this system the cool air is placed in the top, where cooling is most needed, and in the process will carry moisture condensed in the top of the room out of the building. Since warm air rises and cool air falls, cooling is fairly uniform.

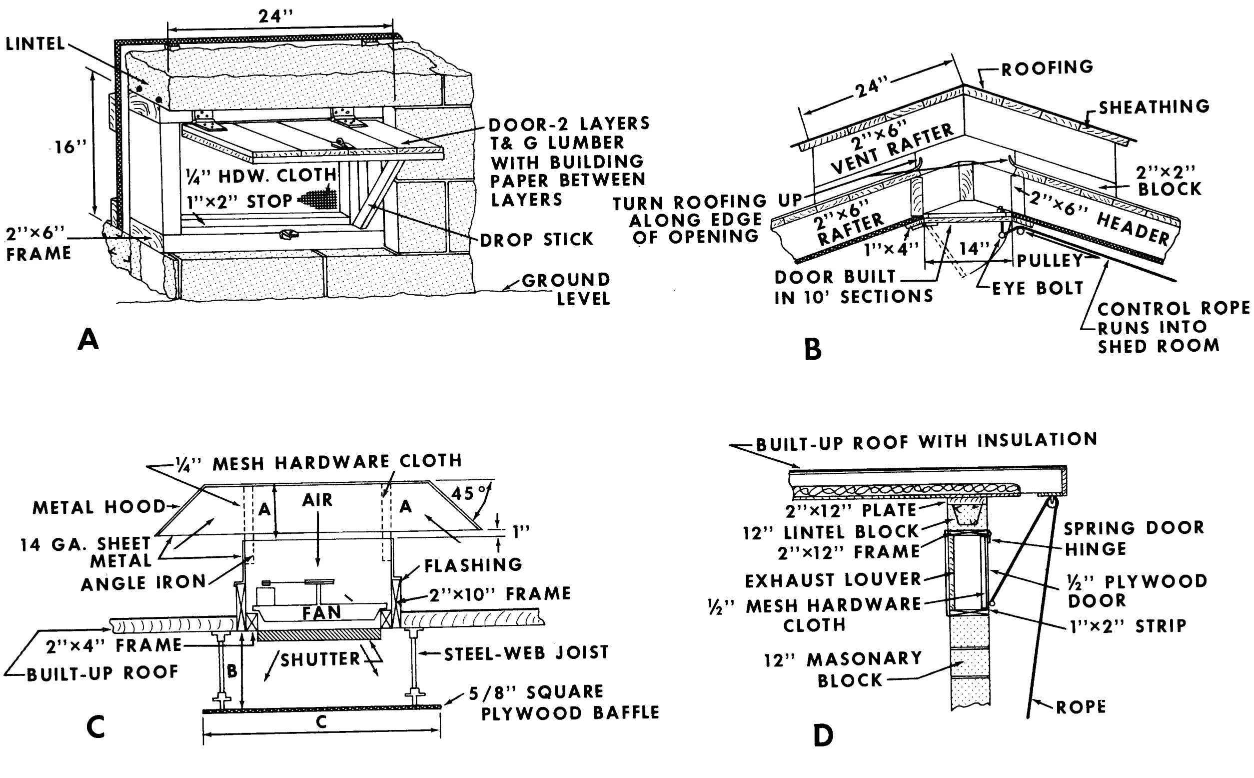


FIGURE 13.—Suggested construction details for ventilating systems: *A*, Air-intake vent at or below floor level for convection-type ventilation; *B*, ridge-exhaust vent for convection-type ventilation; *C* hood and baffle for intake blower mounted in roof of storage room; *D*, exhaust louver for overhead ventilation.

Early in the morning it is not uncommon to find the top of the storage slightly cooler than the bottom. This system works well when outside air temperatures at night average below 55° F.

Overhead ventilation can be made automatic with a timeclock to select the hours of blower operation (usually 8 p.m. to 6 a.m.) and a refrigeration-type thermostat (or sensing element) located near the top of the room. At any time that the temperature in the top of the room is reduced to the desired temperature, about 60° F., the thermostat turns the blower off and chilling is prevented regardless of outside air temperature. Furthermore, if any part of the top layer of sweetpotatoes is cooled below the desired temperature, it is soon warmed by warmer air rising from below.

Since no openings are provided at or near the ground, there is little opportunity for chilling to occur and rodents to enter as when air is introduced into the bottom of the storage room. A differential thermostat may be used instead of a timeclock to provide power to the blower anytime the cooling thermostat is not satisfied and the air outside the storage is cooler than that inside (*73*). Since air is blown into the storage, any air leakage is usually from instead of into the storage.

The blowers should have a capacity of 1 to 2 c.f.m. per 55-pound box of sweetpotatoes at a static pressure of at least 1/10 inch. At least 1½ feet or more clearance should be allowed over the stacked sweetpotatoes to allow for movement of ventilating air. Intake hoods, baffles, and exhaust louvers should provide sufficient cross-sectional area to prevent restriction of the air movement created by the fan. Usually at least 1½ times the area of the fan orifice will suffice for both the intake and the exhaust.

Mechanical ventilation and automatic controls require much less attention than hand operation of ventilation equipment.

Refrigeration

Nearly all operators of large storage houses have some refrigerated storage. Refrigerated storage permits storing roots into warm weather when ventilation is inadequate to maintain low-enough temperatures (*93*). Often the large operator has customers he supplies regularly, customers who want sweetpotatoes throughout the year if they can be obtained.

Cooling sweetpotatoes after curing or during storage with refrigeration involves essentially the same problems and amount of heat as for warming the roots, except that heat of respiration must be removed too. The amount of refrigeration required can be calculated in the same way, except that heat will be moving into instead of out of the storage. In some installations, ventilation has been supplemented with refrigeration, while in others, refrigeration provides all the cooling needed and vents are used only to introduce fresh air.

One approximation of the amount of refrigeration needed for a storage house insulated to produce a thermal resistance of about 10 in the walls and 15 in the ceiling is 4.6 B.t.u. per hour per cubic foot of storage space (*108*). This storage room was designed to hold 8,000 to 10,000 boxes of sweetpotatoes and to maintain 60° F. when temperature outside reached 95° or to cool the sweetpotatoes from 85° to 60° within 10 days.

Another means of estimating refrigeration requirements indicates that approximately 1 ton of refrigeration (theoretically 288,000 B.t.u. per 24 hours) is needed for each 1,000 55-pound boxes stored in rooms insulated sufficiently to maintain the recommended curing temperature with an outside air temperature of 30° F. or lower.

The refrigerated air should be distributed across the top of the storage room and air returning to the unit picked up in the lower part of the room. The refrigeration thermostat may be located in the return air close to the return-air duct if air circulation is continuous, or near the top of the room and away from refrigerated air discharged into the room.

A refrigeration engineer should be consulted since the rated capacity of refrigeration units is often 20 percent less under storage-house conditions than under the customary conditions of testing for home or office use, and thermal resistance of walls and ceilings are slightly different than when heat is lost from the room. Often a blower larger than usually supplied for home use is needed, and the cooling coil should maintain a wet-bulb temperature of 56° F. and a dry-bulb temperature of 60°.

Humidification

At times the moisture given off by the sweetpotatoes, crates, or soil is insufficient to maintain the relative humidity at 85 to 90 percent. This is especially true when large amounts of heat are added to warm cold roots late in the harvest, and during presprouting when the roots and storage containers have come to equilibrium at storage conditions of 60° F. and 85 to 90 percent relative humidity.

Dirt floors, under false floors or racks, can provide moisture. Wetting the soil, if necessary, before the storage season usually provides adequate supplementary moisture. On some occasions water has been run onto concrete floors when the storage containers were up on racks. After the storage house is filled, it is difficult to determine whether the floor is wet and distribution of moisture is often not even. With the development of larger operations, more efficient systems should be considered (*45*).

A mechanical humidifier, which consists of an electrically driven, high-speed fan upon which water is dripped, will produce a fine mist that can be picked up by circulating air and distributed throughout the house. Such a unit is usually mounted where heavy particles of moisture falling from it will not produce undesirable wet areas. A good humidistat may be used to control one or more humidifiers and may be mounted in the return air stream of refrigeration equipment or in an accesible location near the furnace return-air pickup. The humidifier should be mounted at the opposite end of the room from a mechanical refrigeration or heating unit.

A mechanical humidifier should have a capacity of 2 gallons or more per hour for a room containing 5,000 boxes of sweetpotatoes. For presprouting, it should have a capacity of 1 gallon per hour per 1,000 boxes. Unfortunately, the rated capacity of mechanical humidifiers is indicative of the amount of water vaporized or atomized under favorable conditions, but this is only a general indication of its performance under the customary conditions encountered in a storage house. Furthermore, the storage-house manager should be able to check the room's relative humidity and the humidistat for accuracy since the humidistat can easily get out of adjustment. A sling psychrometer is useful for measuring relative humidity (fig. 14) and is more accurate than a stationary wet- and dry-bulb hygrometer because of low rates of air movement in the storage.

Although humidity-indicating devices are easy to use, they are delicate instruments and easily get out of adjustment after a while.

Another method of maintaining relative humidity is discussed here partly because of its simplicity and partly because it puts the moisture in a desirable place. When hot air in trenches is used for heating, water may be introduced into the trench so that the heated air, which is low in relative humidity, may pick up moisture (and lose some of its heat) before it reaches the sweetpotatoes. A drain in the trenches to the outside of the building prevents excessive addition of water and allows for flushing and cleaning the room and trench after storage. The drain should be capped or sealed when not in use. With a little experience, the amount of water to be added can be judged fairly well. Although this system is not automatic, it permits a rapid pickup of moisture when heat is being added to the room. This is also the most desirable time to add moisture. It is better for the warm air to pick up moisture from the trench than from the sweetpotatoes.

An atomizing nozzle placed in the furnace plenum and operated with a solenoid valve actuated by the furnace burner circuit can also be used as a humidifier. Clogging of the nozzle and failure of the solenoid to operate because of variable water pressures however, have produced problems with this system. In addition, use of such a system may shorten the life of the furnace.

The approximate moisture (and heat) requirement for vaporizing water may be calculated as follows:

Vaporizing 1 pound of water will provide all the moisture in approximately 500 cubic feet of air at 85° F. and 100 percent relative humidity or in about 1,250 cubic feet of air at 60° and 100 percent

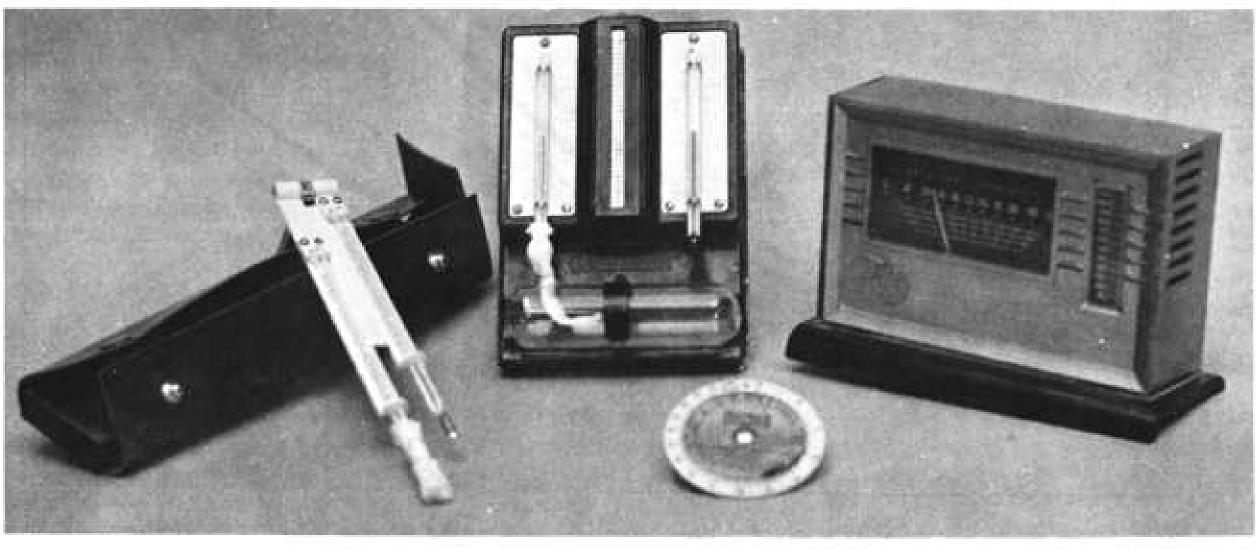


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Figure 14.—Humidity measuring devices: Right, sling psychrometer (that is, portable wet and dry bulb); center, wall-mounted wet and dry bulb with circular conversion scale below; left, indicator actuated by hair element.

relative humidity (fig. 15). Vaporizing 1 pound of water will consume approximately 1,000 B.t.u. of heat.

Insulation and a vapor barrier are needed to permit the maintenance of the high relative humidity recommended (p. 13).

Dehumidification

It is impossible to avoid all conditions that produce relative humidity in excess of that recommended or to prevent condensation at all times. A relative humidity as high as 95 percent is satisfactory for the sweetpotatoes. But at relative humidities of 95 to 100 percent, it is very difficult to prevent condensation. Often the relative humidity rises to 95 percent and above in the storage when the outside air temperature is approximately the same as that inside. Under such conditions a decrease in outside air temperature will produce condensation on any inside surface that is cool enough to be slightly below the storage-room temperature. Whenever the outside air temperature is considerably below inside air temperature, the possibility of condensation exists according to the insulating properties of the walls and ceilings as indicated in figure 8.

Usually excess moisture is removed by ventilation. Air containing less moisture than the air in the storage is introduced to replace some of the air

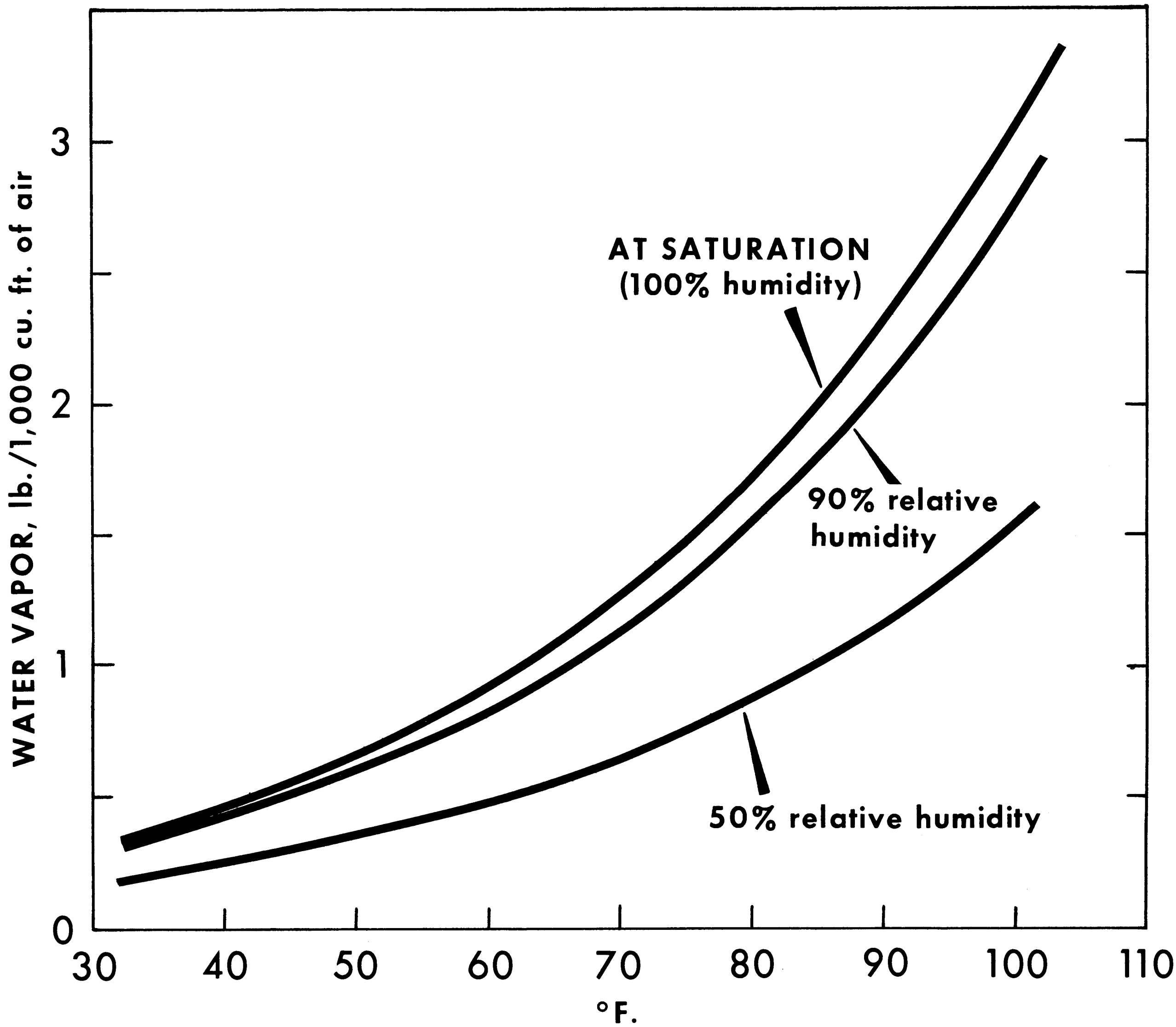

FIGURE 15.—Water vapor content of air at 50, 90, and 100 percent relative humidity.

containing a high level of moisture. Air that is at the same temperature but with a lower relative humidity or cooler air, which cannot hold as much vapor, will reduce the moisture level.

For example, 1,000 cubic feet of air at 85° F. will hold about 2 pounds of water at saturation, but at 63° will hold only about 1 pound at saturation (fig. 15). If 500 cubic feet of saturated 85° air can be removed and 500 cubic feet of saturated air at 63° can be added, the amount of moisture in the air would be reduced from 2 to 1.5 pounds; and if the temperature was maintained by addition of heat, the relative humidity would be reduced from 100 to 75 percent. At 75 percent relative humidity, condensed moisture could be picked up by evaporation into the drier air, if the insulating properties of the wall permit the interior surface temperature to remain above the dewpoint under these conditions.

In effect, then, the moisture content of the air can be lowered by introducing either dry air at the same temperature, or by introducing cold air, and warming it so that, in effect, it becomes dry air at the same temperature. On some occasions a relatively large amount of air is needed to remove moisture and the ventilating system designed for cooling the room may be used. This is additional justification for an efficient ventilating system.

Floor Plans or Blueprints

The floor plans and construction details given here are designed to aid in the development or adaptation of floor plans or blueprints suitable to individual needs, especially in the construction or design of a storage for palletized handling.

Two plans are discussed. The first deals with the procedure for curing and storing roots in a storage composed of several rooms without moving the roots until they are to be sent to market (fig. 11). This has been the recommended manner of curing and storing for many years because it was not possible to move the roots after curing without causing injuries that resulted in considerable decay. The second plan deals with a procedure for curing roots in palletized field boxes (or bulk bins) in one room and moving them after curing to a second room for storage (fig. 12). The last sweetpotatoes cured would not be moved from the curing room unless there was sufficient space for them in the storage room and the storage-house manager wished to move them.

Some features are common to both systems. Posts and other obstructions in the rooms should be as few as practical to permit easy and accident-free operation of the forklift. The turning radius (including the pallet) of most 1½- and 2-ton-capacity forks is nearly 12 feet. Therefore, posts should be at least 12, and preferably 16 or more, feet apart. In planning, 4-foot units or multiples of 4 feet are used since a 44- by 44-inch pallet works well in a storage designed to allow 48 by 48 inches per pallet. The extra space is needed for posts, air passages, allowances for irregular stacking, and leaning of stacks. If another size of pallet is used, similar provision for these features should be made.

Because the turning radius of most forks is 12 feet or less, aisles and doorways are usually 12 feet wide. Doorways should also be high enough to exceed the height of two loaded pallets (that is, about 11 feet for two pallets of Duraboxes stacked five layers high on each pallet). The 12-foot width of the doorway permits stacking all but three rows at right angles to the doorway. These three rows may be filled by driving straight into the doorway. Only space for three pallet loads are lost just inside the door, because a third layer is not possible at the doorway unless the doorway goes all the way to the ceiling. In some instances, double-swinging doors lined with sheet metal have proved useful since the doors remain closed when not in use. The doors shown in figure 11 are too small for best forklift operation.

Because it is practical to stack and unstack two rows of pallets very close together with a side-shifter, and because it is convenient to stack two rows of pallets over a trench for heating, a narrow air channel between each double row of pallets aids in cooling the stacks with ventilation or refrigeration. To illustrate this with 44- by 44-inch pallets, place one pallet close to another over a heating trench so that the pallets touch over the center of the trench. With trenches on 8-foot centers and with reasonably straight stacks, up to 8 inches will be left between this pair of pallets and those centered over another trench 8 feet away. In actual practice the 8-inch space usually becomes 2 to 4 inches. Whatever size of pallets is used, trenches or ducts should be placed to provide even distribution of heat and permit stacking to allow some air channels for ventilation and prevent stacking against outside walls.

A smooth and level floor, including any trenches or registers in the floor, is necessary. A slight unevenness, which may result in as little as ¼ inch deviation from the level between the two front wheels of the forklift, may result in 2 inches or more of sideward movement of a pallet 12 feet off the floor. If the change is abrupt, boxes may shake off the pallet, especially if they have not been properly stacked on the pallet. Ceiling height and clearance over the stacks are determined by container and pallet stacking (p. 6). Usually three pallets with either four or five layers of boxes are used, with five layers per pallet worth considering for field containers less than 12 inches high. The 5-layer-per-pallet load saves pallets, forklift time, and cost of storage space.

The floor should be capable of supporting about

2½ to 3 times the rated capacity of the folklift. It is possible with a 2-ton fork to pick up and move two pallets, one on the other, at one time. In that event, the fork, which is handling about 2 tons, has a counterweight of more than this and the gross weight on the two front wheels may exceed 4 tons. A 4-inch concrete floor poured on firm soil is usually adequate, but this should be confirmed for each site.

Free, unobstructed stacking height should exceed the height of the stacks by at least 6 inches to allow the forklift to raise the top pallet high enough to clear those below and maneuver the pallet into position before lowering it into place. At least 18 inches should be allowed for ventilation over the stacks and to prevent holding the topmost sweetpotatoes too near the ceiling where heat and moisture often accumulate.

Storage With Several Rooms for Curing and Storing

The basic concept in working with a storage composed of several rooms is that enough sweetpotatoes will be harvested in 5 days or less to fill a room. This will permit the room to be kept at 85° F. and 85 to 90 percent relative humidity throughout the period of filling and for an additional 4 or 5 days without excessively curing the first roots placed in the room or inadequately curing the last ones. Each room must be equipped to provide heat for curing and to prevent chilling during winter, ventilation for cooling, aeration, and removal of condensation, and moisture for humidifying dry air. This type of operation requires a sizable investment in equipment for each room if the facilities are to be automatic and thereby ensure good control of curing and storage conditions without considerable time and effort on the part of the storage-house manager. Furthermore, if the investment in such equipment is to be justified and the rooms are to be large enough for efficient use of a forklift, the rooms should be able to hold 2,000 55-pound boxes or more, preferably considerably more.

A final qualification concerning this type of operation is indicative of the number of rooms needed to make the system function properly. If a room is to be filled in 5 days or less, there must be enough rooms to provide at least one room for each week of the harvest season, even if the size of the rooms differs in proportion to the quantity to be harvested each week. Usually no less than four rooms should be used, unless the farming enterprise or enterprises are too small to warrant use of a forklift or the construction of a storage holding 8,000 to 10,000 55-pound boxes of sweetpotatoes. The schematic floor plan illustrated in figure 11 shows operation of two rooms off one furnace and the storage made up of two or more such two-room units.

Although the system of using several separate rooms within the storage house provides a reasonable degree of success in curing and storing sweetpotatoes, it has some disadvantages. The primary disadvantage is the inability to fill a room adequately in 5 days or less on many occasions. The important factors contributing to this are rainfall, which prevents harvesting; breakdown of equipment; inadequate labor supply; and, in cooperatively operated storages, the desire of each producer to put sweetpotatoes in a separate room. The most successful storage-house managers are able to overcome most of these problems except that of rainfall. Lack of success usually means that the curing temperature is reduced to permit slow curing to accompany slow filling of rooms and, eventually, even the elimination of the separate rooms which are not needed with slow curing, although the results are far from those desired.

Storage With Separate Rooms for Curing

With palletization, sweetpotatoes can be cured in palletized field boxes in a room designed to provide recommended conditions for curing, and, after curing, the sweetpotatoes can be carefully moved with a forklift to a room in which storage conditions are maintained continuously. This system provides the recommended curing and storage conditions, but also has flexibility enough to cope with most of the problems that cause irregularities in harvesting. Furthermore, less investment in construction and equipment is necessary than in the system using several storage rooms. More than one curing room or storage room may be used, but available information indicates that curing space should make up one-fourth to one-sixth of the total storage capacity.

This estimate is based on the observation that the turnover through the curing room allows the curing room to handle four to six times its capacity during the harvest period. If the harvest period lasts about 6 weeks and the roots are handled so that they remain in the room about 2 weeks, it would be possible to fill the curing room about four times. If the roots are placed in the curing room and removed on a 7-day schedule, it would permit filling the curing room the equivalent of six times in 6 weeks. The 7-day schedule would fit recommendations regarding the length of the curing period and allow some flexbility by decreasing the time to a minimum of 4 days if necessary.

With this system the palletized boxes may be stacked in rows, two pallets wide over a trench, in almost any order they are received regardless of variety, grower, or quality as long as some identifying mark or tag is affixed to each pallet in a prominent place. If more than one curing room is available, seed roots may be cured in one room and marketable roots in another.

Because of the need to move the palletized units into and out of the curing room several times during a season, slightly more clearance between pairs of rows may be desirable; that is, instead of 8 feet on center for 44- by 44-inch pallets (as shown in fig. 12), heating trenches could be placed on 8½-foot centers or some other comparable arrangement for the size of pallet to be used.

Often three pallets from one grower (or truck) are placed on top of one another to prevent contamination, however slight, from soil sifting down from the pallets on top. A convenient truckload is six pallets. When the palletized boxes are moved to the storage area, the topmost pallets in the curing room should be placed on the floor in the storage area in an effort to keep sprouting at a minimum on all roots. At this time the palletized containers may be sorted into rows according to desire: that is, by grower, variety, quality, intended use (seed, market, processing), or other subdivisions.

The curing room (or rooms) should be equipped to heat, humidify, and ventilate the sweetpotatoes just as recommended for storages with several curing rooms. In the plan shown (fig. 12), furnaces also provide heat in the storage area near outside walls. With proper damper arrangement, a furnace in the grading area may be used to heat this area instead of the storage area. With proper management, the curing facilities may be used for presprouting seed roots in February or March.

The storage area should be equipped primarily for ventilating to cool the roots, although in some areas of production, especially in small storages, some provision for heating to prevent chilling will be needed. The addition of heat to such storage areas need not be as elaborate as in the curing rooms. The storage area should be easily reached from the curing area because forklift time is particularly valuable during the harvest period. Preliminary data indicate one forklift can handle up to 50,000 palletized field boxes in this system with a peak load during the harvest period of about 60 hours of work per week, including some time servicing a grading line.

The forklift is the key unit in this system. A maintenance program for all equipment should be provided, but especially for the forklift. Facilities should be available for prompt repairs or emergency rental of other forklift equipment.

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